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Enabling Digital Capabilities with Technologies: A Multiple Case Study of Manufacturing Supply Chains in Disruptive Times

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Abstract: In the rapidly changing digital economy, manufacturing companies are under growing pressure to adopt new approaches to business management by developing digital capabilities. This research explores the role of digital technologies in enabling these capabilities, using the Digital Capability Model (DCM) as a guiding framework. While previous research often focused on theoretical perspectives, this study operationalizes the DCM by identifying specific applications of digital technologies that enhance business processes. Through a multiple case study methodology, eight manufacturing companies were examined to assess how digital technologies foster the development of digital capabilities. The case studies provide practical insights into the application of these technologies and their impact on organizational resilience and competitiveness, particularly in response to global disruptions such as the COVID-19 pandemic. Our findings reveal that certain technologies are more promising than others for enhancing digital capabilities and that their strategic implementation significantly improves a company's ability to navigate uncertainty. Embracing digital transformation not only mitigates operational risks but also ensures sustainable competitive advantages in an increasingly volatile and complex environment. This research bridges the gap between theory and practice, offering actionable insights for managers to strategically develop and leverage digital capabilities for long-term success.

Keywords: digital technologies; digital capabilities; manufacturing; multiple case studies; DCM; COVID-19

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1. Introduction

Nowadays, companies face enormous pressure and complexity due to globalization, uncertainty about the future, financial issues, an ever-growing amount of available data, and new and stringent rules and regulations. Additionally, the spread of COVID-19 has had a major impact on the global economy, highlighting the shortcomings and weaknesses of global supply chains [1,2]. Major issues have resulted such as supply disruptions, shortages of raw materials and spare parts, restricted transport, and ineffective exchange of information among actors within the supply chain [3]. Moreover, other turbulent geopolitical contexts, such as conflicts and international tensions, have exacerbated these problems, causing further instability and uncertainty [4]. For example, the Russia–Ukraine conflict has significantly disrupted global supply chains, particularly in terms of raw material flows [5]. This has enhanced an already fragile situation, heavily affected by the trade war between the United States and China on global supply chains [6], the semiconductor supply crisis [7,8] and the logistical disruptions and congestion in ports [9] and rail transport in Europe [10].

To support these recent challenges, manufacturing companies need to offset the digital transformation that can support workers and increase companies' productivity. Digital transformation has become an increasingly popular topic for both industries and researchers, since combining digital applications with operational changes can lead to significant performance improvements and competitiveness enhancement [11]. Integrating digital applications with operational changes in the supply chain can lead to significant performance improvements and greatly enhance business competitiveness [12].

Digital technologies serve as crucial enablers for developing digital capabilities in manufacturing supply chains, allowing organizations to boost their operational efficiency and competitiveness through sophisticated digital tools and processes [13–15]. Digital capabilities also enable companies to effectively utilize digital technologies for operational efficiency and strategic innovation [16]. Thus, in this context, digital capabilities play a crucial role in advancing the digital supply chain by improving efficiency and traceability [17,18]. Indeed, digital capabilities are the skills, technologies, and processes that enable organizations to effectively adopt and utilize digital tools to improve their operations and competitiveness [19]. However, a significant gap remains between the potential benefits of supply chain digitalization and the actual outcomes achieved. This gap can be attributed to technological limitations, insufficient knowledge and capabilities, and managerial decisions.

Additionally, the literature highlights several persistent gaps, notably the lack of frameworks that effectively guide the adoption of digital technologies [20]. One of the main challenges for companies and their partners in the supply chain during digital transformation is the lack of consistent identification of the key drivers and enabling technologies, making it difficult to make strategic decisions [21]. Therefore, it is essential to establish a clear and comprehensive framework to guide the digital transformation of the supply chain, develop digital skills, and build digital capabilities [22]. In addition, there is a shortage of empirical research on how digital technologies enable the development of digital capabilities to address supply chain challenges [3]. Indeed, scholars provided empirical studies mainly based on quantitative approaches, leaving a gap in operationally focused research that evaluates the opportunities and application cases of digital technologies for developing digital capabilities in manufacturing supply chains [23,24]. Moreover, existing studies often focus on specific features, such as a particular industry sector [14], or sustainability considerations [25,26], limiting a comprehensive understanding of the broader implications of digital transformation. Moreover, there is a lack of research that analytically examines the diverse enabling technologies, as many studies concentrate solely on a single technology [13,23], leaving the potential synergies between multiple technologies underexplored.

This article aims to explore how digital technologies can enhance the digital capabilities necessary to address recent challenges in supply chains. It falls under the category of theory-building research. Additionally, the article highlights the interaction between digital technologies and capabilities within manufacturing supply chains. It utilizes theoretical insights from both the resource-based view (RBV) and dynamic capability perspectives to examine the key elements of the study.

Specifically, the research questions driving the study are as follows:

- RQ1: What are the main digital capabilities enabled by the adoption of digital technologies in manufacturing supply chains?

- RQ2: How were digital capabilities able to mitigate and reduce the effects of the COVID-19 pandemic?

These research questions are designed to connect the existing literature with the practical challenges faced by manufacturing organizations, making the study's innovative contributions clearer. Unlike prior studies, which often focus solely on either digital technologies or single supply chain challenges, this research offers a novel integration by examining how digital capabilities act as a mediating mechanism between the two. The study further investigates how digital capabilities helped mitigate the negative effects of the crisis, enhancing resilience and efficiency in manufacturing organizations during a period of high uncertainty and instability, such as the COVID-19 pandemic. By evaluating real-world applications, the article highlights best practices and lessons learned, offering insights into how organizations can leverage digital technologies to strengthen their operational capabilities. In doing so, this research advances both theory and practice by offering a thorough understanding of the interdependent relationship between digital technologies and supply chain capabilities. It highlights real case study applications and sets itself apart from the existing literature by emphasizing both capability development and crisis management.

To address the gaps in the literature regarding the practical application of digital capability frameworks and the scarcity of empirical studies on their implementation, we have opted for a multiple case study methodology. This approach offers several advantages for exploring our research questions. By examining multiple cases, we can uncover a diverse range of challenges, strategies, and outcomes associated with the adoption of digital technologies in supply chain management practices.

This paper is structured as follows. Section 2 presents the literature review and theoretical background, providing the foundational concepts and prior research relevant to this study. Section 3 outlines the reference framework and the methodology adopted, detailing the approach and methods used to conduct the research. Section 4 focuses on the case studies, describing their key characteristics and how they were analyzed. Section 5 discusses the main applications derived from the case studies, highlighting their relevance to the research objectives. Finally, Section 6 traces the implications of the paper, presenting the conclusions, limitations of the study, and potential avenues for future research.

2. Literature and Theoretical Background

2.1. Resource-Based View and Dynamic Capability Theory

In today's highly competitive business landscape, manufacturing firms are striving to gain a competitive edge to enhance their overall performance amidst unpredictable market conditions. Achieving this advantage requires a degree of flexibility that enables companies to adjust product pricing, quality, costs, and technological capabilities quickly in response to market fluctuations. Two key theories often used to explain how organizations utilize resources and capabilities to achieve competitive advantages are the resource-based view (RBV) and dynamic capability (DC) theory.

The RBV is a foundational theory applied across various disciplines, including strategic management [27], information systems [28], production, logistics, operations, and supply chain management [29,30]. RBV highlights the significance of a company's internal resources in sustaining its competitive advantage [27]. According to this perspective, for firms to generate business value and sustain a competitive advantage, their resources must be valuable, rare, inimitable, and non-substitutable (Barney, 1991). In information systems literature, RBV has been extensively applied to illustrate how digital technology competencies enhance organizational skills, thereby improving supply chain performance. Digital technology, viewed as a tangible resource, is integrated into organizational strategies to boost capabilities [31].

Despite the robustness of the resource-based view (RBV), its static approach to resource management has faced criticism from scholars [32,33]. To address this limitation, the DC theory emerged as a complementary framework. DC focuses on an organization's ability to mobilize and manage both internal and external resources to adapt effectively to environmental changes [34]. As [35] explains, "dynamic capabilities can be disaggregated into the capacity (1) to sense and shape opportunities and threats, (2) to seize opportunities, and (3) to maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise's intangible and tangible assets".

In the context of disruptions, the existing literature highlights the effectiveness of integrating DC with RBV. For instance, ref. [33] investigated the factors influencing supply chain resilience during the COVID-19 pandemic, finding that disruption orientation and resource reconfiguration significantly enhance supply chain resilience. Similarly, ref. [32] emphasized the role of supply chain risk management practices in supporting resilience during severe disruptions. Additionally, ref. [36] explored the implications of environmental dynamism during the pandemic, integrating DC and other frameworks to address the uncertainty and volatility that demand effective resource management.

Therefore, the RBV and DC theories offer valuable insights into how firms coordinate resources and capabilities to address supply chain risks, emphasizing the need to realign resources and processes for rapid adaptation to disruption threats [37,38].

2.2. Current Research of Digital Capabilities in Manufacturing Supply Chain

Before the rise of digitalization, manufacturing companies relied mainly on traditional factors of production, including land, capital, labor, and established technologies. These elements were essential for developing the capabilities of enterprises, allowing them to gain a competitive advantage in the market [39]. However, relying solely on these factors is no longer sufficient to overcome the weaknesses and risks of very dynamic environments in supply chain management [35]. Companies need to integrate, build and assess both internal and external capabilities to face a rapidly changing and turbulent environment [34]. Moreover, with the onset of the fourth industrial revolution, the manufacturing landscape experienced a profound digital transformation, characterized by the application of emerging technologies to enhance human efforts, streamlining operations and creating new business models. This transformation involves integrating digital technologies into all business areas, fundamentally changing how businesses operate [40,41].

The implementation of digital technologies enables companies to develop digital capabilities, which are essential to enhance their ability and adapt to emerging opportunities and challenges in a dynamic business environment [42]. Ref. [19] described digital capabilities in the supply chain as a set of competencies through which organizations within supply chain networks identify, utilize, and integrate both internal and external digital information and communication technology resources to enhance overall supply chain operations. Indeed, from the perspective of the RBV, resources acquired through digital technology are heterogeneous and possess the VRIN attributes—valuable, rare, imperfectly imitable, and non-substitutable—making data resources essential strategic assets for firms to achieve a competitive edge [26]. In addition, the use of DC theory for investigating capabilities enabled by digital technologies is increasingly popular in the literature [14]. Moreover, developing digital capabilities is even more fundamental for supply chain management as it enhances firm performance by enabling more efficient, adaptive, and responsive operations [22]. This shift underscores the importance of digital capabilities in maintaining the continuity and efficiency of supply chains in an ever-evolving economic landscape [18].

In the digital economy, possessing digital capabilities has become a critical dynamic asset for companies [43].

The impact of technology applications on the digital capability building of companies has gradually drawn more attention from researchers. Ref. [44] investigated how dynamic capabilities powered by big data analytics (BDA) can enhance organizational performance by adapting to environmental changes. Big data, as a form of digital innovation technology, can also play a crucial role in detecting supply chain risks [45], aiding businesses in navigating complex and uncertain environments [46], and addressing social issues within the supply chain [47]. Ref. [48] identified a set of smart capabilities from five base technologies (Internet of Things, Cyber–Physical Systems, big data and analytics/artificial intelligence, and additive manufacturing), affecting production planning and control performances in manufacturing companies. At the same time, digital platforms are extending the supply chain both upstream and downstream, expanding the width and depth of the traditional supply chain network, and changing how supply chain partners collaborate [49]. Digital platforms are also able to accelerate innovation and supply chain reaction [50]. Digital twins enable the capability to make all supply chain aspects transparent by constructing a digital mirror of the physical world [51]. Generative capability enabled by artificial intelligence help facilitate predictive analysis and decision-making among supply chain partners [49]. Furthermore, tools like digital simulation and 3D printing are increasingly incorporated into activities that drive new product value, including ideation, design, testing, and market exploration [52], allowing rapid entry into the market. Additionally, digital technologies, like visualization tools, enable the analysis of partner and competitor activities, as well as industry trends, enhancing the decision-making process [53].

Digital capability development can certainly bring manufacturers a great advantage, but this path has its pitfalls. While on the one hand, the transition towards digital is increasingly an issue of survival and not just an opportunity for improvement [45], it should also be said that achieving the complete benefits of digital capabilities should overcome relevant issues [46]. First, it should be pointed out that the maturity level in adopting the Industry 4.0 paradigm in manufacturing companies is generally quite low, and several organizations are unaware of the basics [54–56]. Moreover, low adoption rates of digital capabilities create a digital divide for SMEs, obstructing their ability to participate in modern supply chains [55,57]. From the supply chain digital disruption perspective, capabilities cannot be denied as key to supporting performance improvement [19]. In addition, the increasingly volatile and uncertain business environment has severely affected supply chains, with global disruptions like the COVID-19 pandemic forcing many companies to suspend operations and sometimes face bankruptcy [18]. In response to these challenges, digital transformation has become a critical strategy for supply chain management. The integration of digital technologies is revolutionizing supply chain operations by enhancing visibility and enabling real-time responses to disruptions [40]. Thus, digital technologies must enable the capability to support top management in applying leadership in leading organizations during turbulent times [58].

The debate on digital capabilities in the scientific literature is an emerging topic, especially regarding developing a framework that identifies which capabilities might be potentially enabled by the digital supply chain. Ref. [19] elaborated a framework to identify the capabilities required to support the transition towards a digital supply chain, while [48] conducted a systematic literature review to develop an analytical framework investigating how smart capabilities influence production and planning control in the Industry 4.0 domain. At the same time, ref. [59] focused on the peculiar characteristics of digital supply networks. While scholars have focused heavily on the identification of digital capabilities to support supply chain management, there is a gap in the literature concerning the practical application of these frameworks and the specific project initiatives to enable them [19,48]. Moreover, studies often adopt quantitative methodologies, such as empirical surveys [50,60] and mathematical models [48], rather than qualitative studies like case studies. Moreover, studies on digital capabilities generally focus on the effects on only a single performance [61], on single processes of supply chain management [37,51], or on single industries [60,62]. In particular, ref. [63] called for the extension of theoretical studies by gathering empirical qualitative data on the role of supply chain capabilities in responding to supply chain disruptions, including natural disasters, political upheavals, and environmental catastrophes.

3. Methodology

3.1. Reference Framework: From the SCOR Model to the DCM

The Supply Chain Operations Reference (SCOR) model is widely recognized for its strategic emphasis on integrating planning, sourcing, making, and delivering processes to link suppliers, manufacturers, and customers effectively. However, in recent times, practitioners have identified several limitations within the SCOR model. One significant drawback is that it often overlooks the dynamic and intricate nature of modern supply networks effectively, also enabled by the introduction of more and more sophisticated digital technologies [59]. In response to these limitations, pioneering scholars proposed viewing supply chains as complex adaptive systems, a conceptual model that better captures supply networks' inherent complexity and dynamism [64].

The Digital Capabilities Model (DCM) represents a critical evolution in supply chain management, particularly in the context of smart manufacturing. Even though it is sometimes described as a "digital extension" of the SCOR model, it builds upon the foundation of digital capabilities introduced within manufacturing operations over the last decade, Digital Supply Networks (DSNs) encapsulate the essence of DCM [59] (Figure 1). Unlike traditional supply chain models, DCM embraces the dynamic and intricate nature of modern supply networks by leveraging advanced digital technologies. Furthermore, the DCM surpasses the SCOR model by moving beyond a siloed view of processes and capabilities, focusing instead on the inter-relationships among various capabilities and overcoming the linear perspective of the supply chain.

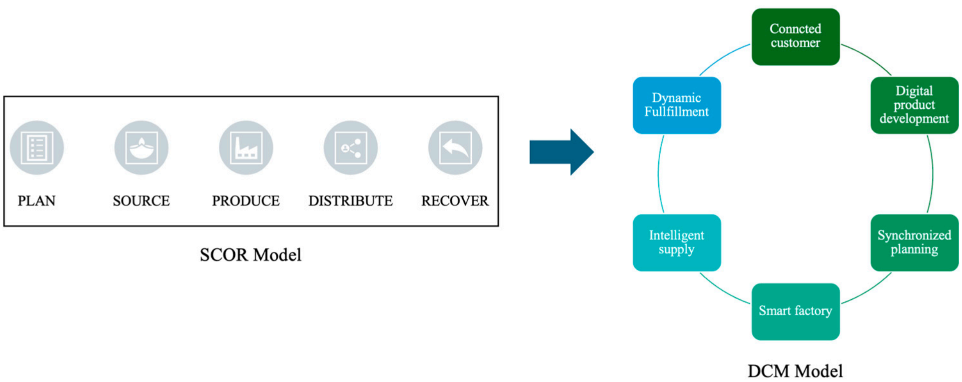

Figure 1. The SCOR model vs. the DCM.

In addition, the DCM takes a capability-led approach, enabling the prioritization of areas that offer the greatest value within the supply network and guiding comprehensive transformation.

At its core, DCM revolves around several six capabilities: connected customer, digital product development, synchronized planning, intelligent supply, smart operations, and dynamic fulfillment (Table 1).

Table 1. The Digital Capabilities Model.

Digital Capabilities	Description
Connected customer	The connected customer capability enables companies to enhance transactional interactions, ensuring effective and cohesive customer engagement across the entire customer, product, and service life cycles, from product acquisition through to service delivery.
Digital product development	Digital product development capability involves creating and managing products and services that are responsive to customer experience and shaped by real-time data, advanced technologies, and agile innovation. This approach directly leads to improved market timeliness, higher design quality, increased productivity, and better communication and visibility.
Synchronized planning	The synchronized planning capability supports business strategy by utilizing planning and operational tools across the entire value network. This capability aligns strategic goals, financial objectives, and tactical supply network plans to develop a connected, concurrent, and synchronized business plan.
Intelligent supply	Intelligent supply represents the evolution of purchasing, sourcing, and supplier management activities. This paradigm focuses on innovation, automation, and end-to-end value creation for the enterprise. Intelligent supply generates insights through advanced algorithms to increase revenue, reduce costs, improve efficiency, and mitigate risks.
Smart operations	The smart operations capability represents an advanced function integrated within the digital supply network, characterized by responsiveness, adaptability, digitization, and connectivity. This approach synchronizes all aspects of production and operations, driving significant improvements in performance and safety not only in manufacturing but also in areas such as quality management and maintenance, repair, and overhaul.
Dynamic fulfillment	Dynamic fulfillment capability allows an integrated, cross-enterprise system designed to improve the customer experience by delivering the right product and service to the appropriate customer or node at the right time, quantity, quality, and condition. It provides supply networks with the desired logistics visibility, responsiveness, scalability, and flexibility.

3.2. Research Methodology

In response to the identified gaps in the literature regarding the practical application of digital capability frameworks and the need for empirical studies investigating their implementation, we have opted for a multiple case study methodology. This approach offers several advantages for addressing the research questions at hand. By exploring multiple cases, we aim to capture the diverse range of challenges, strategies, and outcomes associated with the integration of digital technologies into supply chain management practices.

Moreover, the nature of RQs in this research points towards the adoption of this methodology. By answering the question "how" [65,66], the case studies will provide practical results that will not only help to understand the topic but also give elements to guide its practical application. In addition, case studies can provide detailed information that would go unnoticed in aggregate and top-down quantitative analyses [67,68]. A further value of case studies lies in the possibility of checking the validity of responses due to the nature of personal communication and expertise of interviewees who are most certainly experts on the subject [69]. Finally, by employing a multiple case study approach, we seek to contribute to the advancement of knowledge on the practical implications of digital capabilities for supply chain management, thereby addressing the existing gaps in the literature and providing valuable insights for both scholars and practitioners alike.

3.3. Data Collection and Analysis

Considering the focus of this study on digital capabilities enabled by digital technologies mapped into the DCM, the selected cases are eight manufacturing companies characterized by completed and ongoing digital transformation projects. The cases have been selected using a theoretical sampling method [70,71], focusing on companies that could provide diverse perspectives on the research topic. Specifically, the sample includes medium and large enterprises, as defined by the European Union Commission, operating in different manufacturing industries to ensure heterogeneity. The selection criteria include variations in turnover and number of employees, combined with a shared geographic focus: all eight companies have units of analysis located in Italy, despite operating in various countries. Despite the focus on manufacturing firms and the fact that the choice of a single country may reduce the possibility of generalizing the results, it is ensured that the variation is not caused by extraneous or confounding variables [72,73].

Data collection was mainly conducted through semi-structured face-to-face interviews, conducted between 2022 and 2023. The questionnaire was structured around key themes to gather comprehensive insights from the respondents. It included questions on company and respondent profiles, exploring organizational characteristics, supply chain features, and impacts of the COVID-19 pandemic. Additional sections focused on digital transformation projects, the adoption of digital technologies, and their influence on the digital capabilities from the DCM. Specific attention was given to how digital capabilities supported companies during the COVID-19 pandemic and their expected post-pandemic use.

Since both the participants and the researchers who conducted the interviews were native Italian speakers, the interviews were conducted entirely in Italian. In addition, archival data, including websites, annual reports, and documents on projects, were used to triangulate the empirical evidence. In each company, there were at least two interviewees to improve the validity and reliability of the collected data.

Each interview lasted approximately 90–120 min. All interviews were recorded and transcribed verbatim. A database for each case was created, consisting of the transcripts of the interviews, field notes and archive data. Data coding was conducted in a systematic manner to ensure rigor and consistency throughout the process [74]. Initially, a deductive approach was employed to develop a preliminary coding scheme based on the research framework and existing literature. Subsequently, an inductive approach was applied to identify emerging themes and patterns directly from the data. Coding was conducted manually, and each segment of data was carefully reviewed and assigned to relevant categories. To maintain validity during the translation process from Italian to English, great care was taken to preserve the original meaning of the data. As recommended by [75], both within-case and cross-case analyses were conducted primarily in the original language to minimize analytical biases and content limitations caused by translation [76]. When translation was necessary for discussing, mapping, and presenting the results, multiple in-depth discussions were carried out among the authors to ensure accuracy and fluency, selecting the most appropriate formulations in English.

4. Case Studies

Table 2 provides data on the selected companies scrutinized for this study. Code names are used to protect identity.

Table 2. Case studies' description.

Company Name	Sector	HQ Location	Main Activity Description	Turnover	Interviewee Role
Case A	Coffee Equipment	Italy	Manufacturer of high-end espresso coffee machines	240 M€	Operations director
Case B	Automation	Italy	Design and production of customized automated assembly systems	22 M€	Innovation Manager
Case C	Industrial Automation	Germany	Production of drive systems and gear motors	4.5 B€	Lean Specialist
Case D	Dairy Products	Italy	Production and distribution of dairy products	400 M€	S&OP Manager
Case E	Medical Devices	Italy	Design and production of orthopedic implants and devices	200 M€	Global operations director
Case F	Beverage Dispensing	Italy	Manufacturing and distribution of beverage dispensing equipment	41.5 M€	CEO
Case G	Professional Appliances	Sweden	Production of professional kitchen, laundry, and beverage equipment	1 B€	IT Business solution lead
Case H	Multinational Engineering	Germany	Production of automotive components, industrial products, and consumer goods, including home appliances	91.6 B€	Digitalization and IT manager

4.1. Case Studies Description

4.1.1. Case A

Case A is an Italian manufacturing company that designs and builds high-end coffee machines. Most of its revenue (97%) is generated abroad through a network of global distributors and numerous sales subsidiaries. The company produces coffee machines for both the commercial sector (roasters and coffee shops) and domestic use. Production is made to order, with a small inventory, ensuring a rapid response to demand. Since 2017, the company has launched several digital transformation projects. These initiatives cover areas such as advanced manufacturing techniques, data analytics, and digital marketing, equipping the workforce with the skills needed to thrive in a rapidly evolving industry.

4.1.2. Case B

Case B is an Italian company, specializing in the design and construction of automated assembly systems. The company relies on a complex supply chain involving suppliers of custom mechanical components and standardized commercial components, mostly sourced from Italian companies. Its machines, designed with a high degree of customization, leverage modularity to reduce time-to-market. The company balances customization and standardization in its systems, primarily serving clients in the manufacturing sector, with 60-70% of its business coming from exports, spanning industries such as automotive, furniture accessories, and electromechanics.

4.1.3. Case C

Case C is a German multinational company with a strong focus on people and customers. It is distinguished for manufacturing geared motors, PLCs, and advanced automation systems for smart factories. The company provides drive and automation technologies, industrial gear units, and system solutions that integrate PLCs and software. Serving clients across various sectors including automotive and food & beverage, Case C maintains direct and ongoing contact post-sale.

4.1.4. Case D

Case D, with a history of over 120 years, specializes in the production of high-quality dairy products. The company is renowned for its wide range of offerings, including milk, butter, cheese, and other dairy specialties. Case D sources its milk from a network of local farms, ensuring freshness and superior quality in all its products. The company has implemented key digital projects in recent years with the adoption of digital technologies to optimize production processes and energy savings.

4.1.5. Case E

Case E is an Italian company in the orthopedic prosthetics sector, and it has embarked on an ambitious journey of digital transformation in recent years, with a strong emphasis on adopting advanced technologies to optimize operations and improve customer service. This approach has not only enhanced the clinical effectiveness of prosthetics but also optimized production processes by reducing delivery times and improving device customization. Moreover, the company continues to invest in advanced digital skills, recognizing that continuous innovation is essential to maintaining leadership in the orthopedic prosthetics sector and addressing emerging challenges in the global healthcare market.

4.1.6. Case F

Case F is a leading company in the cold beverage dispenser sector, specializing in the design, marketing, and manufacturing of dispensing systems. It has a strong presence in three distinct markets: flavored water, soft drinks, and beer. Case F stands out for the integrated digital innovation in its products. The company's digital division focuses on advanced customer services, using consumption-based business models, retrofitting, and predictive maintenance. This approach not only enhances operational efficiency but also strengthens post-sales support, setting Case F apart from its global competitors.

4.1.7. Case G

Case G is a multinational company and stands out globally for its extensive operational network, encompassing over 40 legal entities and 11 production facilities scattered worldwide. This dynamic approach not only reflects the agility required to adapt to an ever-evolving market, but also illustrates the operational complexity that the company manages daily. Case G is a leader in the field of professional equipment for food preparation and distribution, laundry, and beverages.

4.1.8. Case H

Case H is a global innovator in engineering and technological solutions, with core expertise in areas such as mobility, industrial equipment, consumer products, and energy management. Operating in over 60 countries, it manages a broad network of 468 subsidiaries, ensuring a strong global footprint. Case H has prioritized digital transformation, focusing on cutting-edge sectors like electromobility, software development, and industrial automation. These efforts are part of its commitment to future trends, including electrification and connectivity, with the goal of developing sustainable, user-friendly technologies.

5. Discussion

5.1. Digital Capabilities Enabled by Digital Technologies in the Supply Chain

Table 3 shows an overview of the key digital capabilities, along with their corresponding applications and the enabling technologies that support the implementation of these applications across different contexts.

Table 3. Case studies' applications and enabling technologies.

DCM Digital Capability	Applications	Description	Technologies	Cases
Connected customer	Connected field service	Connected field services provide a comprehensive approach to managing remote customer service activities and on-site operations using proactive monitoring, mobile devices, and analytical tools. This approach reduces risks, downtime, and costs while enhancing cross-selling opportunities and increasing revenue.	IoT (Internet of Things), AR (augmented reality), Virtual reality, Smart glasses (augmented reality).	Case A, Case B, Case D, Case E and Case G
	Customer management	Customer management is a strategy and set of tools that help customer service representatives address issues and handle feedback effectively, aiming to reduce costs and risks while boosting brand loyalty.	Chatbot and Consumer Feedback Analysis Tools.	Case C and Case D
	Customized experience	Customized experience leverages an organization's digital network to enhance customer communication, engagement, and retention across various channels and devices, enabling data-driven, targeted actions throughout the customer journey.	Video Conferencing Platforms, Online Collaboration Tools, QR Code Technology and Cloud-Based Reporting Platforms.	Case A, Case C, Case D, Case E and Case F
	Frictionless ordering	Frictionless ordering integrates products smoothly into the customer experience by ethically collecting real-time data, aiming to enhance customer success and satisfaction. It streamlines the entire ordering process, from recommendations to a convenient shopping experience.	E-Commerce Self-Service Platforms	Case C and Case E
Digital product development	Enhanced Collaborative Development	Enhanced Collaborative Development fosters improved teamwork and communication throughout the product development process. This capability facilitates seamless collaboration among team members and stakeholders. This collaborative approach enhances transparency, accelerates problem-solving, and aligns the development process with customer needs and market trends.	Augmented Reality	Case G and Case F
	Integrated Systems and Product Optimization	This capability integrates the management of product data across its entire lifecycle, focusing on defining and overseeing both hardware and software requirements. It ensures high data integrity and traceability, which are critical for maintaining product quality and operational efficiency. By leveraging digital tools, it streamlines processes, facilitates effective change management, and enhances overall efficiency. This approach also includes managing test and simulation plans, enabling comprehensive oversight and optimization throughout both product development and systems architecture.	3D Modeling, 3D printing, IoT and Digital Twins	Case G, Case E and Case H
	Accelerated Product Development	Accelerated Product Development refers to the use of digital technologies to streamline and expedite the product development lifecycle. This capability enables rapid iterations, effective testing, and faster market entry. Companies can shorten development times, enhance design precision, and gather real-time feedback, facilitating a more agile response to market demands and customer needs.	3D printing	Case A and Case E

Table 3. *Cont.*

DCM Digital Capability	Applications	Description	Technologies	Cases
Synchronized planning	Comprehensive Inventory and Supply Management	This capability focuses on strategically positioning inventory, managing in-transit supply, and planning future flows to maximize customer satisfaction, profitability, and operational agility. It uses tools such as routing, inventory management, procurement strategies, production planning, and real-time monitoring systems. This capability also includes advanced demand forecasting and real-time adjustments to address supply challenges, optimize resource allocation, and enhance overall supply chain efficiency.	Data analytics tools, custom dashboard, warehouse monitoring software (IoT)	Case A and Case H
	Strategic Business Plan Integration	This capability ensures seamless alignment of strategic, financial, and operational objectives through cross-functional data access and deliberate integration. It involves reconciling corporate and divisional strategic plans with operational plans to forecast demand, manage supply constraints, and address revenue opportunities. This approach enhances visibility into financial performance and ensures that business plans are effectively synchronized with operational realities and market dynamics.	Machine learning-based predictive models, Advanced data analytics	Case H, Case F and Case D
	Responsive Demand–Supply Matching (RDSM)	The Responsive Demand–Supply Matching (RDSM) represents the capability to detect demand exceptions, identify revenue opportunities, and address supply challenges through the planning of constrained resources (materials, labor, equipment capacity) and allocation of supply across the network to best meet demand according to the business strategy. Additionally, it enables a shift towards optimized supply management that respects constraints and aims to maximize profit.	Real-time supply chain monitoring systems, Demand forecasting tools,	Case H, and Case D
Smart factory	Integrated Operational Strategy and Synchronization	This capability integrates strategic planning with operational synchronization. It brings together the creation of a comprehensive strategy that aligns with the overall business vision with the continuous scheduling and resource allocation. This unified approach ensures optimal execution of production and operational activities while enhancing visibility and coordination across the entire network ecosystem.	Scenario-based data model, Data analytics tools, Automated Guided Vehicles	Case F, Case G and Case C
	Advanced Operations Monitoring and Management	This capability integrates real-time operational monitoring and management of support functions. It enables continuous condition monitoring, failure prediction, and management. It also allows for real-time detection of deviations from standards and immediate intervention, thereby enhancing overall productivity and operational efficiency.	Advanced sensors (IoT), Data analytics tools, and digital process twin	Case D, Case F, Case A and Case D
	Augmented Workforce	The Augmented Workface represents an innovative strategy to enhance productivity, capability, and performance in industrial settings by directly delivering alerts and specific information to points of use through command-based digital interfaces, collaborative robots, and image recognition capabilities. These technologies are designed to support workers, reduce waste, and promote a safer working environment. In the realm of smart factories, several companies are adopting advanced approaches to integrate the Augmented Workforce into their operations.	Digital Interface and Collaborative robots	Case G

Table 3. *Cont.*

DCM Digital Capability	Applications	Description	Technologies	Cases
Intelligent supply	Supplier Relationship and Collaboration	Supplier Relationship and Collaboration optimizes interactions and processes with suppliers through structured collaboration and contract management. It integrates real-time visibility, performance monitoring, and proactive contract lifecycle management to enhance partnerships, mitigate risks, and achieve cost savings.	EDI (Electronic Data Interchange, Data Visualization Tools and Real-Time Visibility Technologies	Case E, Case C, Case H and Case D
	Strategic Supply Chain Integration	Strategic Supply Chain and Category Management leverages data analysis and market insights to optimize supply chain performance, predict costs, manage risks, and develop effective category strategies for cost efficiency and value creation.	Sales Forecasting Software, AI-Based Automatic Replenishment Systems and Predictive Analytics	Case A, Case E, Case G, Case F, Case C and Case D
Dynamic fulfillment	Automated and Optimized Transportation Management	This capability allows for automating and optimizing the transportation process from freight tendering to customer delivery. It also includes real-time route optimization to enhance efficiency, reduce costs, and cut delivery times.	GPS Tracking and Dynamic Milkrun Routes	Case H and Case C
	Integrated Order Fulfillment and Data Automation	This capability combines the automation of order management with the transmission of demand and supply signals. It encompasses managing and fulfilling orders across various service points, also including real-time data transmission for order status and fulfillment, enhancing responsiveness and reducing indirect costs.	B2C E-Commerce Platform, Artificial Intelligence and Robotic Process Automation (RPA)	Case C, Case G, and Case H
	Comprehensive Inventory and Integrity Management	This capability focuses on managing inventory and ensuring supply chain integrity. It involves tracking the transfer of custody, inventory movement, and product provenance. It also optimizes warehouse operations to improve order accuracy and inventory management.	RFID (Radio-Frequency Identification), QR Code	Case F and Case H

5.1.1. Connected Customer

The connected customer capability enhances traditional customer interactions by integrating them effectively across the entire customer journey, spanning acquisition through service phases. Leveraging hyper-connectivity and digitalization reduces service costs, improves prediction of customer needs, enhances customer satisfaction and loyalty, and increases overall customer lifetime value. This capability strengthens traditional front-end applications by integrating real-time data from back-end operations, utilizing technologies like signal sensing, location awareness, AI-driven decision-making, and predictive issue resolution. In this vein, Case A has developed a machine monitoring system via an app, enabling the company to be in direct contact with the end customer and to better understand how the customer uses the product and its specific features. At the same time, Case B has a strong focus on field services enabled by digital technologies, particularly for expensive and complex systems delivered in India. The need for continuous support and the desire to reduce downtime is crucial, and remote assistance, including the use of augmented reality, is critical to keep these systems operational. Therefore, digital technologies allow managing remote customer service activities through proactive monitoring of assets, remote interaction, and other preventive measures, as well as on-site via connected mobile devices, customer and issue analysis tools, and automated order management processes. In this way, enterprises and their customers better manage risks and reduce downtime, thereby lowering total labor and service costs and offering greater opportunities for cross-selling to increase revenues. In fact, Case C has implemented on-site customer assistance with a virtual reality application that aids in managing service activities. Additionally, Case E has developed tools through smart glasses that allow for the uploading of all operational techniques, maintaining a strong customer relationship, while Case G is striving to develop a network of connected services, despite some challenges related to security and integration with third-party systems. The creation of a single touchpoint and an IoT platform for real-time monitoring are initiatives aimed at enhancing proactive monitoring and assistance.

These applications also make it possible to build a customer experience that is perceived as highly customized. Online platforms such as the one developed by Case A harness the digital supply network to enhance communication and engagement with customers, addressing their specific needs. At the same time, Case C utilizes internal Opportunity Management programs and e-commerce support to track all interactions on the website and handle personalized customer requests without human intervention. Case D is exploring the use of artificial intelligence to analyze trends and guide decisions on product focus, while Case E has fully digitized its educational and marketing offerings through platforms like Zoom and MS Teams, facilitating collaboration with surgeons, recognized as key opinion leaders, for product development and education via online channels. Finally, Case F provides a personalized experience to end consumers through products like water bottles with QR codes promoting plastic savings and other promotional initiatives. Their cloud services are highly customized in terms of reporting and machine design, emphasizing a targeted and proactive approach to technical support and operational efficiency.

In this context, several companies are adopting digital technologies to improve customer interactions and optimize service management. Case A is developing an online platform to assist customers in managing supplies using connected tools. Case C utilizes Opportunity Management programs and e-commerce support to handle personalized requests without human intervention. Case D has implemented EDI and artificial intelligence to enhance customer relationship management. Case E has digitized its educational offerings through Zoom and Teams, while Case F provides a personalized experience with products like water bottles featuring QR codes and highly customized cloud services.

The seamless integration of digital technologies into products and services also permits collecting real-time product data, aimed at driving customer success in product or service usage and enhancing customer satisfaction. This capability streamlines all processes related to customer product ordering, from providing recommendations to enabling convenient shopping in an environment optimized for customer experience. In Case C, an e-commerce type of online support allows customers to submit detailed requests without human interaction, thereby optimizing the ordering experience and reducing process friction. Similarly, Case E has developed a distributor app that serves as a guided configurator for order placement, eliminating errors and further streamlining the ordering experience for customers.

5.1.2. Digital Product Development

Product development is the process of creating and managing products and services based on customer experience, real-time data, advanced technologies, and agile innovation, aiming to enhance market responsiveness, design quality, productivity, and communication. It enables companies to swiftly conceive, design, and launch customized products and services using modern technologies and a collaborative approach that optimizes the product lifecycle.

Working together ensures more effective communication throughout the entire product development process, facilitating continuous collaboration among team members and stakeholders. In this context, Case F leverages collaboration through augmented reality to showcase prototypes to customers and gather feedback. This innovative approach not only allows for immersive product visualizations but also accelerates the development process by facilitating real-time input and iterative improvements. Case G enables real-time collaboration through advanced document management tools. By utilizing these platforms, teams can seamlessly share and access information, ensuring efficient and synchronized project development.

Similarly, it is essential to be able to manage product data throughout the entire lifecycle to ensure high data integrity and traceability, which are critical for maintaining product quality and operational efficiency. Considering this, Case G adopts the creation of 3D models, the use of digital twins, and an IoT platform to collect defect data, conducting these analyses on prototypes or previous versions of products. This approach helps identify and address issues, thereby improving the design and quality of the final product. Case H employs 3D printing to explore new materials, which is crucial for optimizing components in electric vehicles. This application not only enhances product efficiency and performance but also enables improvements in sustainability by allowing for the development of lighter, more energy-efficient parts using eco-friendly materials and, at the same time, integrates digital components into their products and utilizes 3D modeling to develop more advanced and high-performing solutions. This approach allows for precise optimization, resulting in products that are more efficient and technologically sophisticated. Lastly, Case E implements a PLM (Product Lifecycle Management) system to monitor the entire product lifecycle, ensuring compliance with international standards and enhancing operational efficiency.

In this context, the focus is on leveraging digital technologies to streamline and accelerate the product development lifecycle, enabling rapid iterations, effective testing, and quicker market entry. By adopting this approach, Case A leverages digital technology by using advanced 3D CAD and 3D printing to accelerate product development. This approach facilitates the creation of innovative and customized products while significantly shortening the development cycle, allowing faster iterations and quicker market entry. Finally, Case E employs CAD tools for product design, which not only enhances precision but also accelerates the development process and fosters innovation. This digital approach allows for quicker iterations, enabling more efficient and effective product refinement.

5.1.3. Synchronized Planning

Synchronized planning integrates strategies, financial objectives, and operational plans to facilitate quick decisions, enhance information visibility, and optimize business performance through efficient collaboration and adaptability to evolving market needs.

In this regard, inventory and supply optimization represents a critical capability to strategically position inventory, manage in-transit supply, and plan future flows to maximize customer satisfaction, profitability, and operational agility. This approach leverages various tools such as routing, inventory management, procurement strategies, and production planning. An area of particular focus for companies like CoffeeMatster is the development of customized dashboards to monitor first-level customer warehouses. These dashboards facilitate informed decision-making by suggesting tailored procurement policies, enabling efficient inventory management adapted to geographic variations. Similarly, Case H integrates lean manufacturing principles and real-time production line balancing algorithms to enhance efficiency and reduce production bottlenecks, demonstrating a commitment to continuous improvement and operational excellence.

Similarly, it is important to ensure a seamless alignment of strategic, financial, and operational objectives through cross-functional data access and targeted integration. Case F exemplifies this approach by integrating its business plans with those of its clients using supply chain management (SCM) systems and production planning functionalities in the enterprise resource planning (ERP) system. Specifically, these technologies ensure alignment between operational and strategic plans in the supply of pre-registered materials, thereby improving synchronization and visibility throughout the supply chain. Also, Case H uses dashboard software to monitor Key Performance Indicators (KPIs), which facilitates the reconciliation of its business plans and supports strategic decision-making processes. This technology provides real-time data visualization and analytics, enabling effective tracking of performance metrics and informed decision-making. Eventually, Case D has integrated demand planning into its digitalization processes using machine learning-based predictive models, advanced data analytics, and ERP systems. These technologies optimize the company's response to market dynamics and enhance resource management.

Finally, there is also an effort to effectively detect demand exceptions, identify revenue opportunities, and address supply challenges through the planning of constrained resources and the allocation of supplies across the supply chain to best meet demand. Case H uses dashboard software to monitor Key Performance Indicators (KPIs), which facilitates reconciling its business plans and supports strategic decision-making processes. This technology provides real-time data visualization and analytics, enabling effective tracking of performance metrics and informed decision-making. Case D has integrated demand planning into its digitalization processes using machine learning-based predictive models, advanced data analytics, and ERP systems. These technologies optimize the company's response to market dynamics and enhance resource management.

5.1.4. Smart Factory

The Smart Factory Capability is a highly responsive and adaptive function integrated into the digital supply network, synchronizing production and operations to enhance performance and safety by integrating human and artificial intelligence.

Integrating strategic planning with operational synchronization is crucial to ensure that every aspect of business activities aligns with the overall vision of the enterprise. This synergy not only optimizes operational execution but also enhances visibility and coordination on a global scale, ensuring a more efficient and cohesive network operation. Case F utilizes scenario-based data models to guide its operational decision-making processes. These models allow the company to anticipate challenges and optimize resource allocation with precision by simulating various potential outcomes. This strategic approach ensures that all operations align closely with their overarching corporate vision, driving sustained growth and efficiency. Case G adopts similar approaches, leveraging scenario-based data models to guide operational decisions. By simulating different scenarios, the company can align its production activities more effectively with the global business strategy. This method ensures that resources are optimized, and that production remains in sync with overall strategic objectives, fostering both adaptability and long-term success. Case C manages operation planning through a Manufacturing Execution System (MES). Each Automated Guided Vehicle (AGV) works on a single piece at a time, resulting in a constant flow of 45 pieces being processed, corresponding to the 45 AGVs in operation. The sequence of operations is initially set based on static parameters but is adjusted according to the current plant conditions and workload.

Similarly, real-time monitoring and management of support functions is pivotal for preventing failures and swiftly addressing deviations from standards, thereby enhancing productivity and operational efficiency. Take Case D, for instance, which employs advanced sensors and data analytics tools to manage support functions within a connected operational environment. These technologies enable real-time condition monitoring, fault prediction, and prevention, thereby enhancing overall productivity. Case F and Case G implement efficient support operations in connected environments, using advanced sensors and data analytics to manage operational conditions and anticipate failures, thereby boosting overall productivity. Case A has set up an advanced command center with real-time monitoring and interactive dashboards. Utilizing centralized data visualization and automated alerts, it enables rapid quality control and immediate problem resolution through integrated software and digital communication tools. In the same way, Case D has implemented an operational command center that offers real-time visibility into performance and identifies deviations from standards. By using data science methods to analyze the digital process twin and other enterprise systems, they enable simulations and immediate interventions in the event of anomalies or risks.

Furthermore, implementing advanced technologies like digital interfaces and collaborative robots is crucial for optimizing productivity and ensuring a safer, more efficient work environment. These tools reduce waste and enhance worker support in smart factories. In this context, consider the example of Case G, which has already integrated some components of the Augmented Workforce into its activities. Using digital interfaces, Case G provides precise instructions to furnace operators via screens, thereby improving operational efficiency and supporting personnel.

5.1.5. Intelligent Supply

Intelligent supply revolutionizes procurement by optimizing sourcing strategies, enhancing supplier engagements, and mitigating operational risks. It empowers organizations to secure goods and services at competitive prices, foster innovation through collaboration, streamline internal processes with automation, and proactively manage risks for operational excellence.

Effective supplier interaction and collaboration are essential for optimizing processes and relationships. By integrating real-time visibility, performance monitoring, and proactive contract management, companies can strengthen partnerships, reduce risks, and realize cost savings. Case A implements supplier evaluation dashboards that monitor metrics such as quality and lead times. Similarly, Case E employs standard SRM and KPI tools for real-time monitoring of deliveries and procurement warehouse status, although contracts and framework agreements are not yet fully digitalized. In a comparable manner, Case G uses a CRM (customer relationship management) system for data sharing with suppliers, like Salesforce. This technology enables high levels of structured collaboration and provides immediate visibility into supplier information. Furthermore, Case C manages a significant portion of its procurement operations through SAP, including Purchase Requisition (RDA) management, suggesting high collaboration and real-time visibility with suppliers. Additionally, the company exhibits a strong interest in supplier network collaboration capabilities. Finally, Case H leverages EDI (Electronic Data Interchange) to manage operations with suppliers, providing some structure and automation, albeit lacking references to advanced performance monitoring technologies or enhanced collaboration efforts. In contrast, Case F is developing smart warranty contracts, utilizing advanced digital technologies and contract management software to improve management efficiency, representing an innovative approach.

Moreover, optimizing supply chain performance is crucial for forecasting costs, managing risks, and developing effective category strategies. Leveraging data analysis and market insights is key to ensuring cost efficiency and driving value creation. Case E has implemented a KPI system to monitor real-time deliveries and warehouse status with easily accessible data, suggesting advanced use of analytics for supply chain management. Similarly, Case C's use of SAP suggests deploying analysis tools to forecast and manage costs and supplies, although the scouting process is primarily centralized in Germany. In contrast, Case H utilizes a coded system to collect data on digital modules supporting a KPI system, but the analyses are basic and not related to big data analytics. The company monitors suppliers in detail, especially those from Southeast Asia, suggesting a certain level of analysis and monitoring. Meanwhile, Case D has started using sales forecasting software and AI-based automatic replenishment systems to manage material replenishment. This approach, which relies on advanced predictions and forecasted production orders, reflects a shift toward predictive analytics in procurement. Additionally, Case H uses a digital system, including PIM (Product Information Management) and ERP software, to manage product categories efficiently. This system helps prevent errors and organizes products into classic families, indicating the implementation of category management practices.

5.1.6. Dynamic Fulfillment

Dynamic fulfillment capability implies customer satisfaction by efficiently delivering products and services with precise quality and timing across interconnected enterprises, using advanced technologies and collaborative strategies.

Automating and optimizing the transportation process, from freight tendering to customer delivery, is essential for enhancing efficiency and reducing costs. Real-time route optimization further helps to cut delivery times, resulting in faster and more cost-effective service. Case C uses a transporter tracking system that provides visibility into the transportation status, including delays and necessary route changes. This application allows automating and optimizing the entire transportation process, from freight tendering to customer delivery. Similarly, Case H employs intelligent delivery operations with dynamic milk-run routes (a logistics methodology involving sequential collection and delivery of materials or products from various points in a single optimized trip), demonstrating a certain level of route optimization. However, planning does not occur in real time, suggesting room for further improvement using advanced analytics or cloud computing to optimize routes dynamically and in real time.

Within this framework, streamlining the automation of order management and the transmission of demand and supply signals is essential for enhancing responsiveness and minimizing indirect costs. Integrating order management and fulfillment across various service points, along with real-time data transmission, optimizes efficiency and improves customer satisfaction. Case H has implemented a document digitization system using cameras and artificial intelligence to automate delivery note compilation. This approach automates processes between suppliers and customers, improving operational efficiency and reducing error possibilities. In a similar way, Case C implements an omnichannel management system by consolidating orders from various channels. This approach optimizes logistics processes, reducing both fulfillment time and costs and significantly improving the customer experience. Similarly, in Case G, the introduction of the B2C channel allows customers to place orders directly, which will involve integration with courier systems, marking a step towards adopting an omnichannel approach to order management.

Additionally, managing inventory and ensuring supply chain integrity is crucial for optimizing warehouse operations and improving order accuracy. Monitoring custody transfers, inventory movements, and product provenance is essential for efficient and accurate management. Case F focuses on component traceability by using control units that read the serial numbers of components. This approach ensures that every part can be precisely tracked during the production process. Similarly, Case H represents a model of advanced traceability, with 100% coverage on every finished product. By using RFID technology, Case H aligns the physical world with the digital one and, through the FIFO principle managed with the SAP system, can track every component with extreme precision. Furthermore, Case H employs RFID technology for product traceability and adopts the FIFO principle managed through the SAP system, both of which significantly enhance inventory management and warehouse operation efficiency. Additionally, using advanced technologies to automate the preparation of delivery notes further contributes to operational optimization, reducing processing times and increasing order accuracy.

5.2. Digital Capabilities to Mitigate COVID-19 Effects

The COVID-19 pandemic imposed significant disruptions across industries, challenging companies to quickly adapt through the strategic use of digital capabilities. These capabilities not only helped businesses navigate the immediate impacts of the crisis but also set the stage for long-term transformation in how they engage with customers, manage operations, and optimize supply chains.

Companies like Case G exemplified this by transforming existing technologies from “nice to have” to “must-have”. The surge in the use of augmented reality systems allowed local technicians to receive remote support, ensuring consistent service delivery despite travel restrictions. Additionally, digital platforms for technical training saw a tenfold increase in learners, accelerating the adoption of tools for videoconferencing for both internal communication and external product launches. This ability to maintain cohesive customer engagement across the entire lifecycle, from product acquisition to service delivery, demonstrated the power of a connected customer approach during times of crisis.

Digital technologies also helped enhance product development processes, as highlighted by companies such as Case B and Case E, which leveraged real-time data and advanced technologies to create products that met evolving customer needs. In Case B, the adoption of cloud systems facilitated remote testing across multiple global locations, ensuring that performance standards and contractual obligations were met even when on-site testing was not possible. Moreover, the exploitation of customer relationship management software and knowledge management systems optimized remote collaboration, ensuring that customer interactions remained seamless despite the shift to remote work. At the same time, Case E advanced its digital transformation by integrating AI-based tools and additive manufacturing technologies. This approach improved demand forecasting and enabled the production of customized prostheses, which not only met customer expectations but also positioned the company as a leader in digital innovation within the orthopedic sector.

The synchronized planning capability proved vital for aligning strategic goals with operational realities, especially in a disrupted supply chain environment. Case D maintained its focus on demand planning and Sales & Operations Planning (S&OP), which had been integral to its digitalization strategy even before the pandemic. This approach allowed the company to continue developing a connected and synchronized business plan, ensuring that all aspects of its value network—from raw material sourcing to product distribution—were aligned with its strategic and financial objectives. Case H, another company that leveraged synchronized planning, used remote production monitoring tools to manage operations without the need for a physical presence on-site. By optimizing inventory data control, Case H reduced costs and maintained financial stability, showing how synchronized planning can support both resilience and agility to face unexpected challenges.

Capabilities related to intelligent supply enabled companies like Case A and Case F to navigate the complexities of sourcing and supplier management during the pandemic. Case A faced a surge in demand for home-use products, which doubled their commercial segment. However, the lack of digital interconnection with suppliers initially complicated supply management. Despite this, the company utilized digital technologies to improve procurement planning, effectively preventing production stoppages and ensuring that inventory levels met the increased demand. Similarly, Case F, which experienced a 30% revenue decline in 2020, focused on digital capabilities to manage sourcing challenges, particularly in electronics. The company's focus on intelligent supply not only helped them recover in the following years but also allowed them to continue supporting their customers in understanding and adopting advanced digital services.

In the area of operations, Case C and Case G demonstrated how advanced digital functions could drive significant improvements in performance and operational safety. Case C reorganized work processes through digital tools, which not only improved efficiency but also reduced cultural resistance to the adoption of new technologies. This shift in mindset was decisive in ensuring that the company could continue to operate effectively during the pandemic. Case G took smart operations a step further by investing in Robotic Process Automation (RPA) and other digital platforms. This shift in focus from continuous improvement to future advancements underscored the company's commitment to innovation, although it also highlighted the challenges of change management, particularly in renewing processes and overcoming resistance within the workforce.

Finally, dynamic fulfillment capabilities were essential for companies like Case H and Case E in ensuring that the right products and services were delivered to the right customers at the right time. Case H adopted a "local-to-local" strategy aimed at automating processes and enhancing responsiveness, ensuring that their supply networks remained agile and flexible. This approach was critical in managing logistics and maintaining service quality during the disruptions caused by the pandemic. Case E, meanwhile, developed advanced digital solutions to support surgeons, including a platform that integrated AI for preoperative planning and the production of customized prostheses. By leveraging dynamic fulfillment capabilities, Case E was able to meet specific customer needs with precision, further solidifying its reputation as an innovator in the medical field.

6. Implications, Limitations, and Future Research Directions

6.1. Theoretical Implications

This study examines the enabling role of digital technologies in fostering the implementation of digital capabilities within manufacturing companies to address supply chain disruptions. It expands the existing literature on these topics [14,77] by providing empirical evidence rather than just theoretical potential. While supply chain research has received significant attention in the literature, studies specifically focusing on supply chain dynamic capabilities remain limited [78]. Furthermore, this study adopts a qualitative empirical approach to investigate the impact of supply chain dynamic capabilities on operational performance, drawing on RBV and DC theories.

This research also tested the DCM framework, providing empirical confirmations that reinforce prior theorization on the role of digital technologies in managing turbulent contexts within supply chain management [1,2]. Based on eight case studies, the DCM has been operationalized by identifying specific applications enabled by digital technologies in the manufacturing context. While many studies on digital capabilities have remained at the level of theoretical frameworks, they often fail to delve into the relationship between the adoption of digital technologies and their potential [19,48,59]. We also show the relationship between technologies and digital capabilities through case studies and how some of them are more promising for developing digital capabilities.

Indeed, the focus of this study is not related to a single digital technology [13,23,79], but it confirms the importance of adopting and utilizing digital technologies in an integrated and synergistic manner [16,55]. Furthermore, we find that these supply chain dynamic capabilities are multidimensional and potentially applicable across various segments of the manufacturing supply chain, offering scholars valuable metrics for future research. This study explicitly demonstrates how the digital capabilities of the DCM can be translated into practical applications and their impact on different business processes within manufacturing companies. As a result, this research extends the model to greater depth [59].

Finally, the findings of this research highlight the impact of enabling digital capabilities through digital technologies on mitigating and managing the effects of disruptive events. In recent years, companies across all sectors, particularly manufacturing, have increasingly faced disruptive challenges such as the onset of a pandemic or global crises stemming from conflicts between nations. Since the pandemic's emergence, the literature has frequently concentrated on resilience as the primary capability for addressing turbulent scenarios within the supply chain [22,80]. This study demonstrates how the development of digital capabilities, alongside the digitalization process, enables companies to address the diverse challenges posed by turbulent and unpredictable contexts. It broadens the scope of research beyond resilience by emphasizing the whole supply chain management and its associated processes.

6.2. Managerial Implications

The findings of this study provide actionable managerial guidance for companies aiming to enhance their digital capabilities and adopt digital technologies effectively to address supply chain disruptions. Below, we outline key strategies and recommendations for practitioners based on the research results.

1. Focus on Processes and Scenario Analysis: Manufacturing companies must prioritize an in-depth analysis of their processes in the supply chain, particularly by simulating disruptive scenarios. This approach might allow them to identify vulnerabilities and critical areas where digital capabilities can be developed to mitigate risks and enhance resilience. Companies can model potential disruptions using digital technologies and test different strategies to address them [51]. Such proactive measures enable firms to anticipate challenges and allocate resources more effectively [1,2].
2. Develop a Strategic Roadmap for Technology Implementation: Adopting digital technologies must align with the company's strategic objectives. Managers are encouraged

to create a clear roadmap that integrates digital capabilities into both operational and long-term strategic goals. This roadmap should consider immediate needs, such as real-time supply chain monitoring systems [80], while also fostering a forward-looking vision to enhance competitiveness and agility [58]. By doing so, companies can ensure that digital investments deliver sustainable value across their operations [20,21].

3. Embrace Synergy Through Technology Integration: The findings emphasize the importance of viewing digital technologies not in isolation but as interconnected tools that drive greater impact when integrated [55,56]. For example, case studies revealed how combining IoT sensors with data analytics tools enables real-time operational monitoring and informed decision-making [44]. In other cases, managers should prioritize technology ecosystems that foster seamless collaboration, such as connecting augmented reality tools with smart factory systems to enhance workforce productivity and operational synchronization [81].
4. Extend Digital Capabilities to SMEs: While the study's cases focused on medium and large enterprises, the outlined strategies equally apply to SMEs. Despite their limited resources, SMEs can adopt scalable solutions, such as cloud-based reporting platforms and e-commerce self-service systems, to enhance digital capabilities incrementally [41,82]. Policymakers and industry consortia could also support SMEs by providing access to shared digital infrastructures and training programs to overcome financial and skill-related barriers [54].
5. Accelerate Digital Capability Development: In an era where disruptive events such as global pandemics and geopolitical conflicts have become the norm, manufacturing supply chains must actively cultivate digital capabilities as a strategic priority. The ability to absorb volatility and adapt to changing contexts is critical for survival and competitiveness. For instance, synchronized planning capabilities—such as Responsive Demand–Supply Matching using machine learning-based predictive models—can significantly improve supply chain agility and reduce the risk of breakdowns [83].

By implementing these managerial strategies, companies can enhance their resilience, competitiveness, and ability to navigate turbulent environments. This study expands the managerial understanding of digital capability implementation and highlights its transformative potential across supply chain processes.

6.3. Limitations and Future Research Directions

As with any study, this paper has certain limitations that should be acknowledged. The first limitation concerns our reliance on a model that, although it has been discussed and explored by some academic sources and scholars, cannot yet claim to be a fully theoretically validated reference model supported by many empirical studies. While it provides a useful framework for our analysis, further development, refinement, and in-depth exploration of this model are necessary for it to become a robust theoretical framework upon which other studies can confidently build. Future research should focus on testing and validating this model across different contexts and settings to enhance its generalizability and theoretical rigor.

The second limitation pertains to the case studies used in our research. While the number of cases complies with the guidelines provided by the methodological literature on case study research, our sample is limited to specific contexts and industries. Additional cases from other sectors are needed to validate the results obtained. Expanding the scope of the case studies would not only enhance the generalizability of our findings but also provide a more comprehensive understanding of how the model applies across different organizational settings. Future studies should consider incorporating diverse case studies to test the applicability and robustness of the results across various contexts.

The third limitation is that, like all studies employing the case study analysis methodology, this research is qualitative in nature. While qualitative insights provide deep understanding and rich, detailed data about the phenomena under investigation, they may lack the statistical generalizability offered by quantitative methods. It would be more appropriate to complement our qualitative findings with a quantitative component aimed at strengthening and corroborating the results obtained. Incorporating quantitative data could provide empirical evidence to support our conclusions, enhance the reliability of the findings, and allow for broader generalizations to be made.

Regarding possible directions for future research, one avenue could be the use of other models to validate the results obtained through these case studies. Since this research is primarily based on the Digital Capability Model (DCM), the application of other reference models—such as the Technology–Organization–Environment (TOE) framework or the Dynamic Capabilities Theory—may lead to additional findings or insights. This comparative approach might provide a more nuanced understanding of the factors influencing digital transformation and potentially uncover different aspects of digital capability development.

A second possible direction involves adopting a research methodology based on a systematic review of the scientific literature, aimed at uncovering various technologies' applications for the different digital capabilities identified by the reference model used in this article. By comprehensively analyzing the literature, researchers can map out the current state of knowledge, identify gaps, and understand the diverse ways in which digital technologies contribute to capability development. This approach could also help establish a more solid theoretical foundation for the model and provide practical insights for organizations seeking to enhance their digital capabilities.

7. Conclusions

In an era where disruptive events have become commonplace, implementing robust digital capabilities is essential for manufacturing supply chains to navigate turbulent landscapes. Embracing digital transformation enables organizations to mitigate risks, adapt to changes, and secure a sustainable competitive advantage. By operationalizing the DCM with the identification of specific applications enabled by digital technologies, we have bridged the gap between theoretical frameworks and practical implementation.

Unlike much of the existing literature, which often discusses digital transformation at a conceptual level, this study provides concrete applications for each digital capability within the DCM framework, offering practical insights for organizations. For the connected customer capability, applications such as connected field service, customer management, and frictionless ordering illustrate how businesses can maintain cohesive engagement and deliver customized experiences. In Digital Product Development, capabilities like Enhanced Collaborative Development and Accelerated Product Development showcase how real-time data and integrated systems can optimize product innovation and lifecycle management. In Synchronized Planning, the study highlights applications like Comprehensive Inventory and Supply Management and Responsive Demand–Supply Matching (RDSM), which enable organizations to maintain alignment across value networks, even under stress. For Smart Factory operations, applications such as Augmented Workforce and Integrated Operational Strategy demonstrate how digital tools can enhance operational efficiency and resilience. In Intelligent Supply, Supplier Relationship and Collaboration and Strategic Supply Chain Integration ensure that sourcing and supplier management remain agile and effective. Finally, in Dynamic Fulfillment, applications like Automated and Optimized Transportation Management and Integrated Order Fulfillment and Data Automation emphasize the importance of precision and responsiveness in managing logistics and delivering value to customers. This detailed mapping of digital capabilities to specific applications not only validates the relevance of the DCM, but also provides actionable strategies for businesses seeking to thrive in an increasingly volatile environment. Therefore, the research extends the DCM to a higher depth by explicitly showing how its digital capabilities translate into direct applications that impact various business processes.

In addition, our findings demonstrate how certain technologies are more promising for developing digital capabilities, enhancing competitiveness, and improving resilience against disruptive events. Among the most promising technologies are those related to data analytics and advanced tools, such as machine learning-based predictive models, visualization tools, and custom dashboards, which are essential for optimizing decision-making in complex scenarios. Solutions based on IoT and advanced sensors are likewise critical, enabling real-time monitoring and improving operations and supply chain management. Additionally, augmented and virtual reality and 3D modeling technologies, including digital twins and 3D printing, are revolutionizing production and design processes and accelerating innovation. Finally, the growing adoption of robotics and automation systems, such as collaborative robots, highlights the potential of these solutions to enhance operational efficiency and flexibility, making them cornerstones of the digital future. This provides theoretical insights and managerial guidance on effectively enhancing digital capabilities through targeted technology adoption.

Finally, this research also shows that, during disruptive events such as the COVID-19 pandemic, digital capabilities proved instrumental in mitigating challenges and ensuring business continuity. These capabilities enabled companies to adapt rapidly to shifting demands, maintain operational efficiency, and strengthen customer engagement. For instance, connected customer approaches ensured seamless interactions across the customer lifecycle, leveraging augmented reality and digital platforms for remote support and training. Synchronized planning aligned strategic goals with operational execution, allowing businesses to navigate supply chain disruptions while maintaining financial stability. Intelligent supply capabilities optimized procurement and sourcing, ensuring continuity even under volatile conditions. Meanwhile, advanced digital tools in operations enhanced performance and safety, fostering agility and innovation. Finally, dynamic fulfillment capabilities allowed precise and responsive delivery of products and services, addressing customer needs effectively and solidifying competitive positioning during times of crisis.

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