Digital supply chain capabilities to face the disruption of the COVID-19 pandemic

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Abstract: The troubles in sourcing raw materials and components, as well as logistics bottlenecks due first to the COVID 19 pandemic and more recently to geopolitical tensions and conflicts, have contributed to strong turbulence in the supply chains. To deal effectively with these disruptive events, the mere adoption of digital technologies is not enough, but the targeted development of appropriate digital capabilities is also necessary. The literature has contributed to investigating capabilities in the supply chain, but the topic of digital capabilities to face disruptive scenarios is an under-investigated topic. In this regard, this article aims to answer the following question: How the digital capabilities were able to mitigate and reduce the effects of the Covid-19 pandemic? Therefore, the purpose of this article is to explore the role of digital technologies to enable the digital capabilities that can face the latest supply chain challenges. In addition, particular attention is paid to the role of digital capabilities in mitigating the effects of the COVID-19 pandemic. To this end, this paper adopts the empirical case-study methodology and develops a framework that can serve as a guide for companies facing the challenges listed. This article aims to present the preliminary results of this research, shedding light on the digital capabilities developed by four manufacturing companies, engaged in structural plans for digital transformation.

Keywords: Digital technologies; Digital Capabilities; Supply chain; Covid-19

I. Introduction

Nowadays, companies are facing enormous pressure and complexity due to globalization which increases competition on efficiency and efficacy, procurement lead time, and flow of trade (Simmert et al. 2019). The advent of the Covid-19 virus pandemic has further stressed the fact that the traditional sequential supply chain model is not well-equipped to face challenges related to unpredictable black swan events (Ardolino et al. 2021). To cope with these recent challenges, the supply chain managers need to offset with automation that can support workers and increase companies' productivity. Digital transformation has been a disruptive event becoming 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 (Yang et al., 2021). Moreover, digital technologies (DTs) can support sustainability by enabling circular economy opportunities (Kouhizadeh and Sarkis, 2018; Böckel et al., 2021, Saberi et al., 2019) and marketing by providing necessary data and defining customer profiles (Ardito et al., 2019). DTs can make manufacturing companies and the entire supply chain more resilient to deal with disruptive events, such as a pandemic, as well as make processes more efficient, increase productivity, and make work more reliable and safer for workers (Ivanov, Blackhurst, et al., 2021; Kamarthi & Li, 2020). In addition, the incorporation of such technological drivers must follow an evolutionary process to reach the desired digital maturity level (Frederico et al. 2019). Thus, the introduction of digital technologies has led to the development of new (or at least improved) capabilities to better manage the supply chain: these are called digital capabilities (Sinha et al. 2020).

However, a disparity between potential and actual gains from supply-chain digitalization still exists and can be explained by the technology gap, lack of knowledge, and, in particular, digital capabilities. Several gaps are still evident also in the literature, which can be summarized as lack of development frameworks that provide guidance for DTs adoption, lack of tools and technologies that address supply chain problems in a digitalized environment, investigation on how to overcome the perceived barriers to the implementation of digitalization (Büyüközkan and Göçer, 2018). Furthermore, literature faces a lack of empirical research on how digital technologies enable the digital capabilities to face the challenges of the supply chain. Indeed, digital capabilities enable firms to successfully pursue digital innovations and allow organizations to use digital resources for innovation purposes (Chan et al. 2018; Lyytinen et al. 2016). Digital capabilities are also crucial for the successful implementation of advanced business models such as distributed manufacturing (Srai et al. 2016) and servitised business models (Ardolino et al. 2018). However, it is important to point out that the adoption rates of digital capabilities are creating a digital divide for SMEs, obstructing their ability to participate in modern supply chains (Zheng et al. 2019). The debate on digital capabilities in the scientific literature is an emerging topic, especially with regard to the development of a framework that identifies which capabilities might be potentially enabled by the digital supply chain. While scholars have mainly focused 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 (Queiroz et al. 2019; Bueno et al. 2020). Moreover, studies adopt quantitative methodologies such as empirical surveys (Yu et al. 2018; Brusset and Teller, 2017) and mathematical models (Bueno et al. 2020) rather than qualitative studies such as multiple case studies and longitudinal studies. Qualitative methodologies would be appropriate for the topic in question as they would provide an understanding of the mechanisms that enable the development of digital capabilities, as well as the concrete ways in which they are applied. In addition, studies on digital capabilities generally focus on the effects on only a single performance (Rajesh, 2017), on single processes of supply chain management (Brusset and Teller, 2017; Son et al. 2021), or on single industries (Brusset and Teller, 2017). In particular, Aislam et al. (2020) call for the extension of theoretical studies by gathering empirical data on the role of supply chain capabilities in responding to supply chain disruptions including natural disasters, political upheavals, and environmental catastrophes. To fill the abovementioned gaps, this paper carries out multiple case studies using the digital capabilities model (DCM) as the reference model to investigate the different cases.

In particular, our research focuses on answering the following question: How digital capabilities were able to mitigate and reduce the effects of the Covid-19 pandemic?

The remainder of this article is organized into the following sections. Section 2 discusses the conceptual background. In Section 3, the methodology is presented. In Section 4, the case studies are presented while Section 5 discusses the results. Finally, Section 6 draws the conclusions of this research with limitations and future research directions.

II. RESEARCH BACKGROUND

A. *The digital capabilities model (DCM)*

Before the advent of digitalisation, the main factors on which manufacturing companies built their capabilities were lands, capital, labour, and technologies (Li et al. 2019).

The fourth industrial revolution has completely revolutionized this setting, increasing the need to develop digital capabilities in order to gain a sustainable competitive advantage (Tortorella et al. 2020; Szasz et al. 2020). In the digital age, therefore, the focus has increasingly shifted towards the diffusion of capabilities based on the application of different digital technologies.

The development of digital capabilities might have a major effect on enterprises' performance (Wamba et al. 2017). Rajesh (2017) identifies the technological capabilities able to positively influence supply chain resilience while Bueno et al. (2020) review the literature to shed light on smart capabilities affecting production planning and control performances in manufacturing companies. Similarly, Brusset and Teller (2017) identify a set of lower-order capabilities for supply chain resilience according to the dynamic capabilities approach. In addition, Seebacher and Winkler (2015) adopt a capability approach to evaluate performances related to supply chain flexibility. The deployment of an effective offer characterised by smart services connected to the physical product also requires the development of capabilities enabled by the exploitation of digital technologies and platforms (Ardolino et al. 2018; Eloranta et al. 2021). The development of effective digital capabilities makes it possible to improve the relationship and communication with customers and the diffusion of digital innovative technologies among players in the supply chain is a crucial factor (Obal and Lancioni, 2013).

Therefore, to reach substantial supply chain advantages, organisations should not only be based on the adoption of individual technologies but carefully evaluate their integration (Zheng et al. 2021), also considering the development of business management on strategy and organisation (Queiroz et al. 2019), as well as workers' skills (Cimini et al. 2021). In a digital and global world, the traditional supply chain model is increasingly transforming itself into a network of business partners characterized by flexibility in the supplier base and facilitated electronic data interchange (Sinha et al. 2020). The advent of the Covid-19 virus pandemic has further stressed the fact that the traditional sequential supply chain model is not well-equipped to face challenges related to unpredictable black swan events (Ardolino et al. 2021). It is thus necessary that digital technologies enable capabilities able to support top management to apply leadership in leading organization during turbulent times (Saputra et al. 2022).

The development of digital capabilities can certainly bring a great advantage to manufacturers, but this path is not without its pitfalls. In fact, while on the one hand the transition towards digital is increasingly an issue of survival, not just an improvement opportunity (Nguyen et al. 2018), it should also be said that achieving the complete benefits of digital capabilities should overcome relevant issues, improving performances such as agility, resilience and reliability (Kamble et al 2018; Heriberto-Garcia-Reyes et al. 2022).

In order to answer the research question, this paper carries out multiple case studies using the DCM as the reference model to investigate the different cases. In particular, this model can be considered as a "digital extension" of the Supply Chain Operations Reference (SCOR) model and it includes 6 main digital capabilities, namely: connected customer, product development, synchronized planning, intelligent supply, smart operations, and dynamic fulfillment (Table 1).

TABLE 1
DIGITAL CAPABILITIES OF THE DCM MODEL (ADAPTED BY SINHA ET AL. 2020)

Digital capability	Description
Connected customer	The Connected Customer Capability allows companies to augment traditional transactional interactions to achieve effective and integrated customer engagement.
Digital development	Digital Development concerns a way of developing and managing products and services that are responsive to customer experience and transformed by smart real-time data, advanced technologies, and agile innovation.
Synchronised planning	The Synchronised Planning capability enables a business's strategy via planning and operational levers across the entire value network. This capability integrates strategic goals, financial objectives, and tactical supply network plans to create a connected, concurrent, and synchronized business plan.
Intelligent supply	Intelligent Supply impacts every component of the procurement function to source goods and services from leading suppliers at the best value.
Smart factory	The SmartFactory capability is a highly responsive, adaptive, digitized, and connected function integrated into the digital supply network that synchronizes all aspects of production and operations.
Dynamic fulfillment	Dynamic Fulfillment regards an interconnected cross-enterprise system that enhances the customer experience by getting the right product and service to the right customer or node at the right time and in the right quantity.

III. RESEARCH DESIGN

A. Case studies approach and sample

The purpose of this article falls within the nature of Theory Building research. To this end, this paper adopts the empirical case studies methodology.

This qualitative research methodology, "oriented towards exploration, discovery and inductive logic" (Patton, 2002), is ideal for generating or extending theories and providing pragmatic empirical observations when little is known about a subject or few publications are published (Jabbour et al., 2015; Myers, 2019).

Moreover, the nature of our RQ, i.e., "how" questions, points towards the adoption of this methodology. In this setting, the case studies provide practical results that both help to understand the topic, and give elements to guide its practical application. Moreover, case studies can provide detailed information that would go unnoticed in aggregate and top-down quantitative analyses (Jabbour et al., 2015).

Considering the focus of our study on digital capabilities enabled by digital technologies mapped into the DCM model, the selected cases are four manufacturing companies characterised by completed and ongoing digital transformation projects.

B. Interview protocol and data collection

Data collection was mainly conducted through semi-structured face-to-face interviews. Since both the participants and the researchers who conducted the interviews were native Italian speakers, the interviews were conducted entirely in Italian.

The purpose of this paper and the review reported in section 2, led to defining an interview protocol regarding general information about the company and the interviewees; the digitalisation journey, and the adoption of the digital technologies in the company; which digital capabilities are expressed in the company, through which technologies and projects, and how; how key digital capabilities helped in dealing with the situation generated by Covid-19, how and when they were introduced, and how they help in the post-peak pandemic situation.

In each company, there were at least two interviewees to improve the validity (Yin, 2009) and reliability of the collected data (Voss, Tsikriktsis, and Frohlich, 2002). The interviewees occupy managerial positions in supply chain, manufacturing, logistics and operations. Each interview lasted approximately 90-120 minutes. All interviews were recorded and transcribed verbatim

IV. CASE STUDIES

A. Coffemak

Coffemak is a manufacturing company that designs and manufactures high-end coffee machines, mainly for professional use. Professional customers are mainly coffee roasters and coffee shops. The company has a classic sales model, with two production plants in Italy and several distributors and sales branches spread more or less all over the world. The latter deal with customer contact including sales and after-sales. The company has a small warehouse where the main components are stored, but it works mainly to order.

B. Milkee

Milkee is a company founded in 1900, operating in the food sector, producing dairy products (milk, butter, cheese). The company employs 650 people, with a supply chain of almost 1000. The main characteristic of this reality concerns the fact that it is a first-level co-operative in which the raw materials (milk) come directly from the members, who are also the owners. It has five production plants and one maturing plant.

There is also a logistical platform with 100 pick-up trucks that travel around northern Italy every day to sell the products. Sales take place all over the world in equal percentages in the large-scale retail trade and in the Ho.Re.Ca. and Industry channel.

C. Softbeer

Softbeer belongs to an international group involved in the design, marketing, and manufacture of cold drink dispensers. It operates in three main markets: water (flavoured or enhanced with special minerals), soft drinks, and alcohol (mainly beer). In recent years, a digital division has been created with the aim to create digital services. The market in which the group operates is made up of a few market leaders and several small producers who make up 20% of the market share. The production processes are mainly characterised by assembly activities, although some mechanical bending and stamping are also carried out.

D. Rightankle

Rightankle designs, manufactures, and distributes orthopaedic prostheses working with both the public and private sectors. Nowadays it has 25 subsidiaries in the world. The company mainly works in collaboration with hospitals, through both public and private tender Planning is done according to the customer (hospital) and the real challenge is to supply in 24 hours the required items.

V. Results

A. Connected customer

Connected customer is the digital capability most addressed by the examined cases.

Before the COVID 19 pandemic, Coffemak invested in an advanced videoconferencing system which it adopted not only to facilitate internal communication between the company's various branches, but also to allow customers to have the most direct contact possible in that context. The company has also initiated a project currently being tested by customers in the US involving sensorised products to collect data on how the machines are operating. This, combined with machine networking, allows Coffemak to know in real time how and under what conditions the product is being used by customers. This allows to plan maintenance initiatives or to provide feedback to the customer on how the machine is being used. The data is stored in the cloud, also creating a data pool that the company hopes to leverage for future projects aimed at customers. In addition, for the above-mentioned connected products, the company provides customers with an app with which they can monitor the coffee machine (also remotely), as well as view usage statuses and operating parameters. The app has simple and intuitive dashboards that can be customised to suit the customer's needs.

Milkee has implemented an artificial intelligence engine that is able to extract specific patterns from searches made on the Internet by end consumers. This information is taken into account and integrated into the demand planning phase, anticipating customer needs.

Softbeer is developing intelligent warranty contracts. The warranty starts from the moment of installation, but varies depending on how the product is used. If the machine is used correctly by the customer, the manufacturer extends the warranty. Based on data collected from connected products, the company also provides an advanced service based on predictive maintenance. Among other connected customer initiatives, the company has sought to have intelligent contact with existing and potential new customers. Indeed, during COVID 19 it was not possible to participate in trade fairs, so the company organised digital days using virtual reality to show existing and potential customers its new offers and product ranges.

Rightankle's customer are surgeons, i.e. those who will implement the implants. In normal times, surgeon training on specific prostheses and product development in collaboration with the surgeon would take place in person, with cadaver sessions and hands-on testing. Covid 19 has made this impossible and the theoretical and practical training has been brought into digital via the Zoom Teams platforms - it has also brought the entire training offer and marketing information into digital. In addition, smart glasses providing instruction on operating techniques were adopted to facilitate training for surgeons. The company has also developed apps that make it easier for customers to place orders with distributors; through the app, distributors have a configurator that guides them in filling the order. This eliminates all errors on orders.

B. Digital development

Two cases reported initiatives related to digital development.

Softbeer started using virtual reality to show customers pre-prototypes of new machines. Customers were able to verify the geometric, aesthetic and functional characteristics of possible new products using hololens and provide feedback to improve them, thus contributing to collaborative design. Moreover, connected products equipped with sensors and networked with Softbeer enable the collection of usage data; this data is analysed in real time and analyses are carried out to evaluate possible improvements to the product itself. Similarly, the design of new products takes into account data collected from other products to evaluate improvements and solve critical problems. In addition, in a project still under development, all data is analysed and used to feed a digital twin for design.

Rightankles uses the 3D printer to test and then ensure the compatibility of prostheses and avoid rejection crises. In addition, it has a platform to develop the product together with the surgeon.

C. Synchronised planning

Two cases reported recent projects concerning synchronised planning.

As described above, the artificial intelligence engine implemented by Milkee by extracting specific models from searches made on the Internet by end consumers can do advanced demand forecasting that supports demand planning. In addition, a digital twin system has been implemented for the production planning process which, through a simulation process, will propose to the planner a first scheduling proposal taking into account all the process parameters collected from the various production assets (setup times, changeover times, availability of raw materials, etc.), with a feasibility check of the plan.

Rightankles has also adopted artificial intelligence for demand planning. Artificial intelligence is used to analyse orders and identify patterns and physical characteristics in the population of countries where the company has customers that may result in different needs on the prosthesis.

D. Intelligent supply

All cases reported difficulties in sourcing raw materials during COVID 19; two of them described recent projects specifically to improve the intelligent supply capability, which has become extremely important.

Coffemak is working with some of the most important component suppliers to integrate systems and transmit real-time stock information. This information should enable an automated supply order process. The company was already aware that this was necessary and was already present in many of its competitors, but the COVID 19 situation has made the need clearer and no longer deferrable.

Rightankles is trying to evaluate its suppliers in order to understand which ones are the most reliable, to stimulate improvement in all of them and to do analysis to prevent any problems. In doing so, they aim at developing a robust data analysis system using KPIs on real-time delivery progress, purchase stock status and date management.

E. Smart factory

Three cases reported projects concerning the smart factory capability.

Coffemak has developed a series of apps to manage its production processes. All operators are equipped with tablets and through these apps they can follow and update in real-time the progress of production, check planning, scheduling of work, and control the incoming material. These apps dialogue directly with the company's ERP system. In addition, the company has been using KANBAN logic to supply its warehouses and assembly stations for some time; all stations and containers have been equipped with RFID tags on which all information is written in real-time by the operator using tablet apps. This facilitates the real-time monitoring of stocks and the traceability of components and products.

At the Milkee manufacturing plant, all production lines and service machines (for heat and cold generation) are sensorised. Data is collected and processed in real-time by a system of big data analytics and artificial intelligence to improve the efficiency of asset use. The machines self-manage according to their states of use, with the aim of minimising energy consumption.

Rightankles implemented an MES software for advanced planning through real-time production data retrieval. In addition, in February 2020, at the dawn of the COVID 19 pandemic, Rightankles became the first company in the world to open a factory made up of 3D printers inside a hospital, piloting the initiative at a customer site in New York. Production became smart as it was completely cloud-based. This project was extremely useful during the pandemic because the surgeon, the customer, could see the prosthesis that the printer was producing in real-time on-site, there were no shipping times, which during the pandemic could be enormously extended, and the lead time was drastically reduced, being able to intervene promptly in serious cases.

F. Dynamic fulfillment

On the digital capability dynamic fulfillment, Coffemak described the previously mentioned project concerning the implementation of an advanced videoconferencing system linking the head office with all sales branches and distributors worldwide. This project was implemented prior to the pandemic, and although it has only been in constant use since the pandemic began, the knowledge of it has helped greatly to avoid the shock of switching to remote working. It made communication with customers and suppliers very smooth in an environment where direct communication was the most commonly used and no longer physically possible. Of course, the system does not allow for true dynamic fulfillment, but it does facilitate communication and the tracking of documents and chats that help to avoid misallocations. In addition, the company worked to create a digital skill matrix, a matrix that correlates individual workers with their skills. Based on these skills and the processing of a small artificial intelligence engine, the application proposes an assignment of jobs to operators based on their skills.

VI. DISCUSSION

Most if not all of the projects in the case studies described above enabled the development of specific digital capabilities that contributed to improving profitability and competitive advantage over competitors. From the preliminary analysis carried out in this article, a series of sub-capabilities were distinguished for each capability, which are described in Table 2.

TABLE 2
DIGITAL SUB-CAPABILITIES OF THE DCM MODEL

Digital capability	Sub-Capability
Connected customer	Effective and smart communication with the customer; Interactive and customised customer experience; Development and delivery of advanced services for the customer; Anticipation of customer needs; Development and delivery of advanced services for the customer
Digital development	Collaborative design with the customer; New product development according to field data
Synchronised planning	Advanced demand forecasting; Smart planning
Intelligent supply	Automated supplying process; Supplier analytics
Smart factory	Real-time updating of production process information; Traceability within organisational boundaries; Efficient management of production assets; Manufacturing as a service
Dynamic fulfillment	Effective communication at all nodes of the supply chain; intelligent job scheduling

All the projects described were implemented according to a specific strategic digital transformation plan, independently of the advent of the COVID-19 pandemic. In fact, all the project initiatives described refer to long-term plans that were initialized before the COVID-19 virus spread. However, the digital capabilities developed because of these digital transformation projects had the positive side effect of reducing, or at least mitigating, the effects of the pandemic.

In the case of Coffemak, having already implemented an advanced videoconferencing system a long time ago, the transition to remote working was very smooth and went without a hitch. In addition, contact with customers has been smooth and relatively effective.

At the same time, for Softbeer, using augmented reality to engage customers in product design helped a lot at a time when travel was limited due to country restrictions to reduce infection. The adoption of Artificial intelligence has also helped Rightankle to have good accuracy of trade demand and also to evaluate information on the population of the countries and the products it needs.

The implementation of digital technologies in the case studies under review in this article also reduced the strong demand impacts caused by the pandemic. The sensitisation of production assets implemented by Milkee, combined with data collection and the use of big data analytics to optimise and efficiently utilise resources, helped reduce the effects of overloads due to unstable demand in the early pandemic period. At the same time, when product sales were at a standstill caused by the pandemic, the provision of some paid services on the connected machines ensured a minimum of incomes stability even during the weeks of forced closure (Coffemak, Softbeer). Moreover, with the implementation of the first 3D printer factory inside a hospital in NEW YORK by Rightankle, the surgeon can check and see the prostheses that the printer is producing - dramatically reduced the lead time especially for severe cases.

It is therefore clear that the adoption of digital technologies in the case studies enabled the effects of Covid-19 to be addressed.

VII. CONCLUSIONS

This paper has provided preliminary results about a research concerning the development of digital capabilities in manufacturing companies. In particular, this study focuses on the effects of digital capabilities in mitigating the effects of the Covid-19 pandemic. The preliminary identification of the digital capabilities has been carried out based on the DCM framework.

A limitation we face is that our study is purely conceptual – despite our use of illustrative cases to practically show our conceptual findings. Therefore, further empirical research is needed. The list of digital capabilities we have proposed through the DCM model should be further investigated since they could offer relevant advancements in the analysis of the effects of digital transformation of manufacturing companies in disruptive contexts.

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