Available online 27 March 2025

The Interplay of Agile Capabilities in Crisis Response

Abstract

Purpose - Large-scale disruptions that lead to extreme environmental uncertainty, combined with perceived threats and time pressure, have prompted some organizations to rapidly form new networks. This research focuses on how actors in these newly formed networks leverage their agile capabilities in response to extreme disruptions."

Design/methodology/approach - Grounded in the agility literature, this study employs an abductive research approach and a multi-case design. Data were collected from 18 actors embedded in four newly formed networks located in the United Kingdom, Italy, Colombia, and the United States.

Findings - Through six propositions and an empirically derived model of supply chain agility under extreme uncertainty, the findings reveal a dynamic interplay among agile capabilities. They also illustrate how the utilization of these capabilities shifts in environments characterized by severe unpredictability.

Practical implications - The research underscores the importance of allocating equal attention to both cognitive and physical dimensions of agility. Under conditions of extreme uncertainty, firms may need to adopt more entrepreneurial behaviors to enhance agility; however, this can increase risk exposure, which must be managed proactively.

Originality – This study contributes to the body of knowledge on supply chain agility by identifying the interrelationships between agility dimensions and demonstrating how extreme uncertainty influences their practical application.

Keywords: Supply Networks, Agility, Extreme Uncertainty, Supply Chain Risk

Introduction

The COVID-19 pandemic disrupted societies and economies worldwide in unprecedented ways, creating formidable challenges for organizations across all sectors. Beyond causing a global public health crisis, the pandemic also triggered a profound economic downturn (Sodhi & Teng, 2021). A key driver of these disruptions was the highly transmissible nature of the virus, which led to an immediate surge in demand for personal protective equipment (PPE), such as face masks, face shields, gowns, and respirators. Traditional healthcare supply channels struggled to meet this demand, due in part to the unprecedented scale of demand and in part to a reduction or complete loss of manufacturing and logistics capacity (Cohen & van der Meulen Rodgers, 2020).

Faced with these challenges, many organizations exhibited remarkable agility by mobilizing resources and forming new supply networks with partners outside their primary industries. Hewlett-Packard Inc., for example, leveraged its 3D printing technology to produce essential PPE, including face shields, mask adjusters, and hands-free door openers (Sheffi, 2020). Ford joined forces with General Electric and 3M in March 2020 to accelerate the production of ventilators and respirators for patients experiencing breathing difficulties (Mishra & Klayman, 2020). In the United Kingdom, luxury fashion brand Burberry repurposed its manufacturing capacity to produce and donate over one hundred and sixty thousand pieces of PPE, mainly surgical masks, to the National Health Service (BBC, 2020). These examples illustrate the surge in distributed manufacturing capacity within newly formed supply networks that rapidly emerged to address urgent needs.

Building on the existing literature on supply chain agility (Christopher, 2000; Swafford et al., 2006; Cerruti et al., 2016; Gligor, 2016; Müller et al., 2023), we seek to understand how network actors utilized agile capabilities to respond rapidly to market demand under extreme uncertainty and within newly formed supply networks. To guide this investigation, we adopt Gligor et al.'s (2013) framework of agile capabilities, which distinguishes cognitive (alertness, accessibility, and decisiveness) from physical (swiftness and flexibility) dimensions. Treating supply chain agility as a multidimensional construct allows for a more nuanced analysis of how these capabilities are developed and interrelated in contexts marked by extreme uncertainty.

Using a theory elaboration approach with abductive reasoning (Ketokivi & Choi, 2014), we conducted a multi-case study (Yin, 2009) of four newly formed networks that arose to address critical supply shortages during the COVID-19 pandemic. These networks, located in Colombia, Italy, the United States, and the United Kingdom, were established by organizations volunteering resources to produce essential products such as PPE and ventilators. Despite operating in diverse geographical settings, the networks shared common characteristics that enabled us to construct a process model of supply chain agility and support our findings with theoretical propositions.

This work makes three key contributions. First, through our process model of agility, we show that cognitive and physical capabilities are closely connected, indicating that focusing solely on physical dimensions of agility, often a managerial priority, constitutes a necessary but insufficient condition for effectively responding to external changes (Gligor et al., 2013, 2022; Yang, 2014). Second, we demonstrate that responding effectively to extreme environmental uncertainty, perceived threat and time pressure to act, requires "extreme agility." This level of agility is achieved only when network actors adopt more proactive, risk-taking, and innovative behaviors (Covin & Slevin, 1988; Lumpkin & Dess, 1996), thereby embracing an entrepreneurial orientation in decision-making and executing decisions with swiftness and flexibility. Third, our findings offer practical guidance for organizations looking to strengthen their agility and resilience in the face of disruptions. Specifically, we provide a framework to develop and sustain agile capabilities that enable rapid, effective responses to unforeseen challenges, while simultaneously managing potential risks.

The paper proceeds as follows. First, we review the theoretical background on agility and situate our work within this literature. Next, we detail our methodology and explain our data collection and analysis procedures. We then present within-case displays and cross-case analysis, capturing our theoretical insights in a series of propositions and an empirically grounded process model. Finally, we discuss the theoretical and practical contributions of our work and conclude with an examination of limitations and directions for future research.

Theoretical Background

Agility has traditionally been conceptualized as a set of capabilities, such as alertness, responsiveness, flexibility, swiftness, and decisiveness, that organizations deploy to manage environmental uncertainty and create competitive advantage (Goldman et al., 1995; Zhang & Sharifi, 2000, 2007; Gligor & Holcomb, 2012; Gligor et al., 2013; Gligor, 2016). Initially, these capabilities were viewed through the lens of individual organizations. However, scholars have increasingly extended the concept to entire supply chains, contending that establishing interorganizational relationships allows the entire network to respond more effectively to environmental turbulence (Christopher, 2000; Van Hoek et al., 2001; Swafford et al., 2006; Cerruti et al., 2016). In their review of supply chain agility literature, Al Humdan, Shi, and Behnia (2020, p. 292) compare multiple definitions and conclude that supply chain agility refers broadly to *"the ability of an entity to respond to changes in a timely manner,"* where the *"entity"* may denote either a single organization or a network of organizations.

Agile supply chains exhibit distinctive features—such as heightened sensitivity to environmental changes, rapid information exchange, and an aptitude for orchestrating networks to achieve flexibility—that make them particularly relevant in disaster relief operations (Kovács & Tatham, 2009; Day, 2014). Accordingly, Kovács and Tatham (2009) assert that when organizations and governments respond to a disaster, they must swiftly mobilize resources and capabilities to move from a *dormant* to an *agile* state.

Various frameworks have been proposed to examine the capabilities and practices that underpin agility (Zhang & Sharifi, 2000, 2007; Swafford et al., 2006; Vázquez-Bustelo et al., 2007; Blome et al., 2013; Gligor & Holcomb, 2012; Gligor et al., 2013; Gligor, 2016). Despite some variation in emphasis, these frameworks generally depict organizations responding to environmental uncertainty by combining capabilities and practices to enhance financial, operational, and relational performance. Table I summarizes the main characteristics of these frameworks.

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For the present study, we draw on the work of Gligor and colleagues, who identify five agile capabilities and categorize them into two overarching dimensions: *cognitive* and *physical* (Gligor et al., 2013). Cognitive capabilities focus on information processing to determine which actions to take and include:

- *Alertness:* The ability to quickly detect changes, opportunities, and threats.
- *Accessibility:* The ability to access relevant data regarding how to address environmental changes.
- *Decisiveness:* The ability to make resolute decisions about how to respond to changes.

Physical capabilities refer to the execution of decisions and include:

- *Swiftness:* The ability to implement decisions quickly.
- *Flexibility:* The ability to modify the range of tactics and operations to the extent needed.

We adopted this framework for several reasons. *First*, it is grounded in both theoretical and empirical research (Gligor & Holcomb, 2012; Gligor et al., 2013; Gligor, 2016). *Second*, it draws on the relational view (Gligor & Holcomb, 2012), aligning well with our focus on newly formed supply networks. *Third*, it explicitly links agile capabilities to the environmental uncertainty that drives agility (Gligor & Holcomb, 2012).

Agile capabilities and extreme uncertainty

Environmental uncertainty is widely recognized as a key driver of agility (Zhang & Sharifi, 2000; Zhang, 2011). Indeed, the level of uncertainty influences the specific capabilities required for an agile response (Pil & Cohen, 2006; Koka & Prescott, 2008), as operating in high-velocity markets demands different capabilities than those needed for moderately dynamic environments (Eisenhardt & Martin, 2000). When turbulence is severe, agility entails navigating unanticipated changes and surviving unprecedented environmental threats (Zhang & Sharifi, 2000), manifesting as "the ability to reorganize rapidly and smoothly, whereby the end state or situation needing change is not established a priori" (Bernardes & Hanna, 2009, p. 42). This study investigates agility in the context of *extreme environmental uncertainty,* characterized by substantial and discontinuous change (Sirmon et al., 2007). Such uncertainty drives extreme market unpredictability due to abrupt shifts in demand and supply, whose effects ripple throughout the broader economy (Sodhi & Tang, 2021). As shown by Skipworth et al. (2022), the COVID-19 pandemic amplified this uncertainty, resulting in a widely perceived threat and creating a sense of urgency for network actors to act under time pressure (Müller et al., 2023). The agility literature distinguishes between operational and dynamic capabilities, namely, the capabilities that enable an organization to *"earn its living now"* versus those that enable an organization to *"change the product, the production process, the scale, or the customers (markets)"* (Winter, 2003, p. 992). Given that agility centers on managing organizations in turbulent environments, many agile capabilities can be considered dynamic. Nonetheless, organizations may also respond to uncertainty by relying on ad hoc problem-solving modes—even within their operational capabilities—through quick, high-paced, and often opportunistic adjustments to maintain performance (Winter, 2003).

Although Gligor et al. (2013) highlight that the five agile capabilities share a common theme, they do not elaborate on the interrelationships among these capabilities. They propose a sequential logic, in which cognitive capabilities drive decision-making and physical capabilities carry out those decisions, implying a causal link between the two. Recognizing that capabilities are interconnected, prompts the need for a process model to clarify these relationships. To our knowledge, no prior work has empirically tested such a process perspective on agile capabilities. Past research has also established a positive relationship between agility and firm performance, including benefits such as enhanced relational performance (Gligor & Holcomb, 2012), operational performance (Fernandez-Giordano et al., 2022), and customer and cost effectiveness (Gligor et al., 2015). However, these studies primarily focus on routine business dynamics rather than the unique conditions arising from extreme events.

Agile capabilities and newly emerged networks

Despite the valuable insights noted above, the role of agility, and more specifically, how network actors utilize agile capabilities, within newly formed supply networks remains underexplored. A supply network is an organizational arrangement composed of individual firms linked upstream and downstream to deliver products and services to end consumers (Choi & Hong, 2002). While such networks can include numerous firms, research suggests that their fundamental building blocks are triads, making it critical to examine at least three-way interactions to understand network behavior (Choi & Wu, 2009).

Newly formed supply networks often arise to achieve shared objectives—such as boosting efficiency, fostering product innovation, or responding to external threats (Harland et al., 2001; Gulati, 1998; Son et al., 2021; Skipworth et al., 2023). They emerge in recognition that existing supply chain structures may not be sufficient to manage the complexity and uncertainty present in the external environment (Choi et al., 2001; Harland et al., 2001). By leveraging the complementary strengths of multiple partners, these networks can cultivate flexibility and responsiveness (Christopher & Holweg, 2011; Gulati, 1998). Additionally, their lack of legacy systems and entrenched processes often positions them to adopt agile practices from the outset (Ketchen & Hult, 2007; Gunasekaran et al., 2008). This inherent adaptability is a hallmark of agile supply chains (Swafford et al., 2006).

At the same time, newly emerged networks face significant challenges, including the need to build trust among diverse participants, coordinate differing organizational cultures, and navigate the risks associated with supply chain integration (Cousins & Menguc, 2006; Gulati, 1998). Furthermore, because these networks are nascent, they may lack established risk management processes, leaving them more vulnerable to disruptions (Narasimhan & Talluri, 2009).

Recent research by Müller et al. (2023) offers valuable insights into how agility supported the COVID-19 response, documenting how organizations adopted a temporary, ad hoc orientation to build supply chains capable of coping with emergent crises. They observed that agility in this context often required risk-taking behaviors. Yet, while these findings are illuminating, Müller et al. (2023) treat agility predominantly as a monolithic, network-level construct.

Given that agility has frequently been examined as either a single concept or as a set of separate, non-interacting capabilities (Gligor et al., 2013), an important gap remains in understanding how agile capabilities interact—particularly under extreme uncertainty and within newly emerged networks. This gap underlines the need to investigate the interdependencies among cognitive and physical capabilities, as well as the ways in which network actors deploy them in emergent supply networks. By illuminating these processes, we can develop a more nuanced understanding of agility that advances both theory and practice in dynamic and uncertain environments.

Methodology

The purpose of this research was to unveil how organizations in newly emerged supply networks utilize agile capabilities in response to extreme supply network disruptions. We adopted a theory elaboration approach with abductive reasoning and developed our insights utilizing a multi-case study approach (Yin, 2009; Ketokivi and Choi, 2014). Case study research is suitable for investigating novel questions and concepts, particularly of how and why type (Edmondson & McManus, 2007; Yin, 2009; Denzin & Lincoln, 2011). It is also well aligned with a theory elaboration approach, where researchers aim to research in-depth relationships between concepts, introduce new concepts or examine boundary conditions of an existing theory in a new context (Whetten, 1989; Fisher & Aguinis, 2017). To ensure the validity and reliability of our study, we applied a series of measures, that are summarized in Table II.

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Case Selection Criteria

The unit of analysis in this study was the individual actor (i.e. an organization, this being a buyer or a supplier), and the unit of reference was the newly formed network of actors involved in the design, manufacturing, distribution, and use of PPE and medical equipment. Drawing on replication logic (Eisenhardt, 1989; Meredith, 1998; Patton, 2002), we established three key case selection criteria based on literature and preliminary field observations:

1. *Extreme Environmental Uncertainty:* The selected cases had to be exposed to severe environmental uncertainty stemming from substantial and discontinuous changes in factors such as market structure, supply–demand dynamics, or abrupt external shocks

(Sirmon et al., 2007). The COVID-19 pandemic introduced widespread disruptions (Sodhi & Tang, 2021), particularly within the healthcare industry's PPE and medical device sectors. We therefore focused on geographic areas where hospitals experienced a significant need for PPE or medical devices amid disrupted supply chains, risking potential halts in medical services if alternative sources were not found.

2. *Formation of New Supply Networks with Non-Traditional Healthcare Suppliers:* In response to unprecedented demand and disrupted supply, many hospitals began seeking assistance from organizations that had never previously supplied to the healthcare industry but possessed manufacturing resources and capabilities (e.g., to produce masks or face shields). These rapidly formed, time-bound networks (Müller et al., 2023) provided a unique opportunity to examine how agile capabilities are deployed across multiple tiers of network actors.
3. *Network Completeness:* Each newly formed network had to include (a) a healthcare buyer of PPE or medical devices, typically a hospital, and (b) at least a few non-traditional suppliers involved in the design, manufacturing, or provision of PPE, medical equipment, or essential parts. We required at least three actors per network to meet the minimum triad criterion (Choi & Wu, 2009). Additionally, these suppliers could not have had any pre-existing commercial relationships with the healthcare buyer or with other network members, ensuring that each network was genuinely newly formed. The only exception to this criterion was the supplier (VisCut) in Case 3 (the visor network), which was an existing supplier but had previously worked on a completely different product.

Data Collection Process

Prior to data collection, we designed a semi-structured interview protocol grounded in extant literature and initial field observations. The interview guide comprised three main themes:

1. The impact of the COVID-19 outbreak on each actor and its network.
2. The actor's response to the outbreak, emphasizing agile capabilities.
3. The outcomes of that response.

Starting in mid-2020, we monitored public information sources (e.g., Johns Hopkins University, the CDC) and media reports regarding firms' responses to the pandemic. We combined this with outreach to local hospitals to investigate how they were addressing PPE and medical equipment shortages. Through this process, we identified four hospitals in distinct networks, each located in a different region (the United States, Italy, the United Kingdom, and Colombia). Hospital management teams were informed of the study's objectives and the case selection criteria and were asked to facilitate introductions to other network participants.

By late 2020, we had gained access to four newly formed networks, encompassing a total of 18 actors. Each participating firm designated individuals who possessed both technical and commercial expertise relevant to the study, thereby enhancing the accuracy and depth of the data. We conducted semi-structured interviews with these representatives and enriched the findings with secondary data from public news reports, company documents, product descriptions, photographs, manufacturing site images, and process walkthrough videos. In Cases 3 and 4, not all firms could be interviewed directly due to confidentiality restrictions. Following Wu and Choi (2005), we addressed this by conducting additional interviews with other participants, extending interview durations, and triangulating these insights with secondary data sources. All interviewees participated voluntarily and consented to having their interviews audio-recorded and transcribed for analysis. Table III summarizes the key details of the selected cases and is further elaborated upon in the subsequent within-case analyses.

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Data Analysis

Data analysis proceeded iteratively, involving a cyclical process of data collection, analysis, and theoretical refinement (Strauss, 1987; Strauss & Corbin, 1998). Insights into how network actors employed agile capabilities emerged after multiple rounds of theorizing and reviewing the case data. This iterative engagement with both empirical data and existing theory aligns with abductive reasoning in theory elaboration, which entails adapting general theoretical logic to accommodate contextual nuances (Ketokivi & Choi, 2014). During open, axial, and selective coding, we identified constructs traceable to established conceptualizations. However, the iterative interplay between data and theory can also reveal previously unrecognized constructs or relationships (Fisher & Aguinis, 2017), which we formally capture in our propositions and empirical framework.

Given that we employed a multi-case study approach across 18 organizations, particular care was taken to reconcile differing interpretations among the research team. All interviews were initially coded by at least two researchers, and any coding discrepancies were then addressed through collaborative coder meetings (Miles et al., 2014). In line with Miles et al. (2014, p. 81), *"Frequent coder meetings to negotiate differences in coding are a crucial part of the process, enabling the construction of a shared understanding of the data while simultaneously checking for potential biases or misinterpretations."* Through this process, the research team held structured discussions to revisit direct quotes, relevant literature, and the conceptual context surrounding each point of disagreement. For instance, in one case, a participant's statement on network response time was categorized as "decisiveness" by one researcher and "swiftness" by another. By reviewing the original transcript and discussing the nuances of cognitive versus physical agility, all four researchers ultimately concluded that the quote referred primarily to speed rather than resoluteness. This iterative approach helped us arrive at a shared coding scheme, which was then applied uniformly across all data, thereby strengthening the consistency and credibility of our findings.

Within-Case Descriptions and Analysis

Below, we briefly describe each of the four cases examined in this study. To maintain brevity, we have included all tabular displays of the within-case analysis in Table IV (Appendix 1), where we provide detailed information on the individual firms within each case network. This approach allows us to proceed directly to the cross-case comparisons, in which we capture our findings in six propositions and an empirical framework.

Case 1 – Masks: During the COVID-19 outbreak, a U.S. hospital chain (MasUser) encountered a severe disruption in PPE supply. In response, two local companies—a shoe manufacturer (MasMan1) and a printing/signage company (MasMan2)—stepped forward upon realizing the hospital's critical shortage. Under the guidance of the hospital's procurement team, doctors, and nurses, the two companies rapidly developed prototypes within three days and delivered the first batch of usable PPE in one week, despite having no prior experience with health products.

Case 2 – Valves: An Italian hospital (ValUser) was unable to source oxygen mask valves from its usual suppliers due to a surge in COVID-19 cases. A local R&D firm (ValDes) designed a valve to adapt a snorkeling mask into an emergency oxygen mask and made this design freely available online. Consequently, various 3D printing companies, including Val3D, produced these valves. Meanwhile, a plastic molder (ValMold) volunteered to industrialize and manufacture the valves on a large scale, ultimately producing approximately 150,000 valves for global distribution.

Case 3 – Visors: In the United Kingdom, a major automotive manufacturer (VisDes) recognized the PPE shortage and decided to help. Within three weeks, it had designed and tested a visor prototype in collaboration with local hospitals. An existing supplier (VisCut) cut the polycarbonate visor, initially paired with 3D-printed headbands. As demand grew, VisDes switched to injection molding within ten days, thanks to a molding specialist (VisMold). After a few months, VisDes returned to its regular business activities, while VisMold continued manufacturing and assembling the visors.

Case 4 – Ventilators: In Colombia, a university (VenDes) anticipated a ventilator shortage and assembled a multidisciplinary development team to design an emergency ventilator. They identified local suppliers for critical components, including a specialized testing company (VenTest) that conducted laboratory simulations in close coordination with regulatory bodies. A military factory (VenMan1) and a domestic appliance manufacturer (VenMan2) were tasked with production, while both a civilian hospital (VenUser1) and a military hospital (VenUser2) participated in testing. Remarkably, the team managed to develop and deliver a functional ventilator in just two months, significantly faster than the usual 6–10-month timeframe.

Cross-Case Analysis and Proposition Development

Extreme environmental uncertainty and the cognitive capabilities of agility

The global health crisis caused by the Covid-19 pandemic led to significant uncertainty in the firms' operating environment. Network actors faced disruptions in raw material supplies, high fluctuations in customer demand, logistical disruptions, and shortages of workers. These factors, combined with the perception of threat to society, exerted immense pressure on firms to respond swiftly and find solutions to disrupted PPE flows.

The analysis of our case data revealed that extreme environmental uncertainty, combined with perception of threat, influenced all three cognitive capabilities of agility, however not in the same way. Across all cases, managers became much more alert to changes in the external environment due to the rapidly changing and uncertain environment, which manifested itself in constant news monitoring about the pandemic spread and regulatory changes; a shift to daily, or even hourly, checks of supply needs with hospitals; and accelerated engagement with suppliers to find parts, components, and ways to manufacture PPE. As the manager of ValUser put it, *"It happened that a wave of patients arrived in the emergency room within a few hours. Clinicians began asking for oxygen therapy devices, so masks, helmets ... we were able to respond at first, then, after new orders were issued, the deliveries [from the usual suppliers] were incomplete. I found myself on a Friday when they call me and tell me that oxygen valves were missing … it was necessary to find the way to build them"*. Furthermore, we found that with increased alertness, decisiveness also increased. All actors had to respond quickly to accelerate decision-making, under the extreme uncertainty and perceived sense of urgency, to ultimately ensure the rapid supply of PPE for patient treatment in response to the looming health crisis. As highlighted by VenUser1 "*When the pandemic started in Colombia, we were expecting something similar to what was happening in Europe … We saw from the news that many patients in Italy and in Spain were sharing ventilators and that is very dangerous – so one ventilator for 2, 3 or 4 patients – normally one ventilator is used by only one patient. … So in order to avoid patients having to share ventilators or patients dying without ventilator intervention we decided we needed to have a ventilator that could be manufactured very rapidly, it would be easy to source components within the Colombian market and it would be a low cost ventilator*".

In contrast to the increase in actors' alertness and decisiveness, accessibility to relevant information on how to deal with the extreme environmental uncertainty, and associated changes, was very limited. It is important to bear in mind that hospitals' response to PPE supply shortage required new supply networks, often involving suppliers not hitherto part of the healthcare sector, to supply newly designed products under uncertain demand. For this reason, and particularly in the early stages of the response to PPE supply disruptions, network actors dealt with a significant shortage of relevant information and informational ambiguity related, but not limited to who is going to coordinate the response; what will demand for PPE look like in weeks ahead; who are and where are the suppliers with necessary manufacturing capabilities; product design information and testing; usability, safety and functionality of PPE for the end users and patients. A telling example of the unpredictability of demand for PPE is captured by one of the managers at ValDes: *"When we contacted one of these[hospitals], we asked him if he needed masks, he told me, "I still have them in stock, to be super calm I would need 10-20". Based on that we made the calculation: consider 20 masks per hospital, we have 4 hospitals in emergency, that's 80 masks. Assuming that a fifth, sixth or seventh hospital also arrives [to an emergency situation], 100-150 masks should be enough. This was a production that we could have done* *easily. During the [next] 3 days the situation deteriorated dramatically. Therefore, we found ourselves having numbers 100, 1000 times greater than those estimated."* Given the above evidence, we propose:

Proposition 1: In newly formed networks, extreme environmental uncertainty, coupled with perceived threats and time pressures, heightens actors' alertness and decisiveness but does not necessarily enhance their accessibility.

This proposition advances our understanding of how specific cognitive dimensions of agility contribute to responding to environmental uncertainty. We build upon Gligor et al. (2013) and Gligor (2016) by demonstrating not only the individual roles of cognitive dimensions but also their directional responses. Furthermore, we deepen the understanding of the relationship between external environment and cognitive dimensions of agility by revealing that a distinct context - characterized by above-normal environmental uncertainty, perceived threat, and time pressure - can diminish informational accessibility.

Alertness has been considered a critical element of supply chain agility, enabling firms to detect changes in their operating environment, with the most emphasis being on detecting changes in customer demand. Our case analysis reveals the need to significantly broaden what firms should be alerted to. The reason for this is that supply chain disruption of the magnitude and scope of the Covid-19 pandemic caused disruptions on at least four levels: individual level – (e.g., workers or their families getting sick), firm-level (e.g. firm's loss of human or financial resources, and/or production means), supply-network levels (e.g. supply disruptions across multiple tiers, significant fluctuation in consumer/customer demand) and in the broader domestic and global environment (e.g. governmental regulations/de-regulations, policies regarding Covid-19 shutdowns).

We found evidence across all four cases that the actor's attention to customer demand changes was insufficient to coordinate a swift response to the multi-level disruptions and consequent uncertainty and change. Network actors had to pay close attention to their internal ability to act swiftly and modify their product development, sourcing, and manufacturing processes to manufacture and distribute products they had never produced before.

Equally important was detecting changes, threats, and opportunities in supply market availability in order to readjust rapidly. For example, VisDes had to constantly monitor the supply market for Polycarbonate, because of the sudden shortage caused by a global demand increase: *"Polycarbonate became like gold-dust globally – it was being used for visors, it was being used for guards on the protective screens in shops – so all of those types of things had the same clear type of Polycarbonate".* Similarly, MasMan2 had to go swiftly and continuously back and forth between material availability on the supply market and the product design team, in order to ensure the alignment between mask design features and material availability: "*We had to go back to our purchasing team and say "here is the materials". What can you do?" and that really became part of our procurement area working back and forth saying "They have this material, would this material work?" "Here is the price point, will that price point work for what we are trying to do to help them out. So there was a lot of back and forth and there is a lot of stock out like "we would not have this for three weeks, but we have an alternate material. will this work?""* Another example is ValMold that changed radically its planning procedures: *"Our production plan normally has a multi-week horizon but clearly became daily, completely upset the company's work logic. The emergency has however led to reflections and beyond the* *punctual management of critical issues also in the logic of risk assessment"*. Given the above evidence, we propose the following:

Proposition 2: In newly formed networks, an actor's alertness to extreme environmental uncertainty is contingent upon its capacity to sense changes in swiftness capability, the supply network, and customer demand.

This proposition expands our understanding of how network actors sense and detect changes across their networks. While Li et al. (2008) established that agile supply chains must remain alert to changes in their chains and surrounding environment - including customer feedback, emerging trends, and demand pattern - we extend this scope to encompass both the supply side of actors' networks and their capacity for swift, timely responses to change. This broader perspective is particularly crucial given the increasing magnitude, scope, and multi-level nature of disruptions, as evidenced by the COVID-19 pandemic.

As argued in Proposition 1, extreme environmental uncertainty and simultaneous perception of threat impacts cognitive agility capabilities. When it comes to decisiveness, our analysis unveiled an additional and important nuance. Specifically, it became apparent that managerial decisiveness increased despite the unclear, missing or conflicting information that managers had (or lacked) about various aspects of the crisis response including ambiguous / unknown demand, lack of supply sources, product design and safety. We attribute this increase to the time pressure to act swiftly or to paraphrase a sentiment of multiple involved participants – "*to help doctors saving lives*".

There was a clear pressure in moving forward even if with products that still needed finetuning. As highlighted by VisDes "*We were like, let us get it out first, we get feedback and we will adapt because it is more important for you to get something in your hands and give us feedback than us take three four-five weeks to try to perfect it.*" Similarly ValDes CEO stressed that "*speed was the fundamental key. It is not that our project was the best ever in the Covid arena*" and, reviewing a few other Covid-related project who did not manage to have an impact in spite of their potential, he mentioned that it is "*because they did not have enough speed from concept to creation and therefore too much time passed by*". The relevance of decisiveness is captured in the following quote by VenDes, *"We knew that INVIMA [The National Institute of Drug and Food Surveillance in Colombia] would need to approve that product and we knew eventually INVIMA would ask for clinical trials that might make it impossible to have the ventilator available for the peak of the pandemic in Colombia but we took the risk of doing that [breathing ventilator] anyway."* Given the above evidence we propose the following:

Proposition 3: In newly formed networks operating under conditions of extreme environmental uncertainty, an actor's (information) accessibility and alertness positively affects decisiveness.

This proposition advances our understanding of the interconnected nature of cognitive dimensions in supply chain agility. While prior research has suggested potential relationships between these dimensions (e.g., Overby et al., 2006; Gligor, 2016), empirical validation has been lacking. The existing literature has typically treated cognitive dimensions (as well as physical dimensions) as distinct constructs without examining their potential interdependencies. Our proposition specifically demonstrates how two cognitive capabilities, information accessibility and alertness to changes, influence an actor's decisiveness in strategic decision-making.

The interplay between cognitive and physical capabilities of agility

Swiftness, in terms of implementing decisions quickly in reaction to the needs of the community and extremely unpredictable and changing environment, has been recognized in all cases as a key pillar in their Covid-19 response strategy. For instance, MasMan1 stated, *““We went from basically never making one of these things [PPE] and in a week, we are making eight thousand a day … we had our whole group in here just getting the factory ready and streamlined and hiring people and everything… We clean out the portion of the factory and then we moved our machinery from our current production environment into a new area and then completely sanitized that area with the machinery. Basically, completely made a new factory”*.

Flexibility in terms of the ability to modify the range of tactics and operations to the extent needed has also been a key attribute highlighted in all cases in their response to the pandemic. For example, in the Visor case, VisDes explained that, *“the final version was molded, but initially we had a 3D printed one, which was the first one we brought to market because we needed to get things out really, really quickly – and we had a number of external companies who were actually 3D printing them [the headbands] for us”*.

Both for swiftness and flexibility, evidence from the cases indicates that physical agility was made possible by the changes in cognitive agility capabilities: alertness, accessibility and decisiveness. As VisDes described “*I don't think we put too much thought into it because I think sometime you can dither too much and think ‘is this or is that the right product and we'll go with a, b, c and we'll go with all of these PPE solutions and we'll test all of them…’ and we would have still been there 3 weeks later trying to decide what was the right solution to design and* *develop – so we really didn't need to think too much about it – it was really responsive and we just said 'you need this – we've got a way of doing it'*".

As discussed in Propositions 1 and 3, the perceived threat and sense of urgency boosted decisiveness (ability to make decisions resolutely) as all actors had to make decisions in a steadfast manner to enable a swift response. In the Visor case VisDes decided to make a visor rather than other PPE, due to demand, and fit with their capabilities, and VisMold resolutely offered their services by purchasing steel for injection molds before VisDes gave their commitment to order. This clearly increased the swiftness with which they could switch to higher volume injection mold production, also demonstrating high flexibility in operations.

In the Valve case, the ValDes made a resolute decision to share the 3D printing valve design file on their website, "*we found ourselves with demand a 1000 times greater than estimated….. we have six 3D printers, we will never be able to satisfy the request. What do we do? Do we want to earn? No. Well, then we upload the file to our site and anyone who has a printer, since the piece is simple, can print it and send them [the valves] directly. So we did, it wasn't planned*". This led to swiftness, where ValDes was quickly able to access 3D production capacity at a worldwide scale, and flexibility, where production volume could be scaled up.

In the Mask case, driven by high levels of willingness to respond to the health crisis, MasMan2 made resolute decisions throughout the entire face shield development and manufacturing process, which increased the speed of NPD, reducing it from a multi-week process to less than a week. Further, this series of resolute decisions enabled flexibility in re-purposing manufacturing equipment and new-skilling of workers, allowing the shift from printing and sign making to face-shield manufacturing at MasMan2. Given the above discussion, we propose the following:

Proposition 4: In newly formed supply networks operating under extreme environmental uncertainty, an actor's decisiveness directly influences its physical agility capabilities, specifically swiftness and flexibility

While existing literature acknowledges potential connections between cognitive and physical capabilities of agility, most studies do not explore interrelationships of cognitive and physical dimensions of supply chain agility (Blome et al., 2013; Gligor et al., 2013; Yang, 2014). With this proposition we empirically demonstrate that cognitive and physical capabilities, while distinct, are intrinsically linked. Improvements in physical capabilities—both swiftness (speed of response) and flexibility (scope of tactical modifications), follow enhancements in cognitive capabilities, thus requiring the development of both capability types.

Physical agility capabilities and outcomes

Across all cases, it was evident that the new products added value to those in need. The ventilators were being used even at the pilot stage of development, because hospitals had run out of ventilators, and they needed them to save lives. Whether it was masks, valves, visors, or ventilators, all the organizations expressed being praised by members of their communities, who recognized the value of their efforts.

Increased swiftness was shown in the design to manufacture time and increased flexibility in the adjustments in the production planning. For example, in the Visor case, VisDes highlighted that "*we did that [the visor development] in a number of weeks, around 3 weeks – so it was really fast. So from the initial asking 'can we do something?' to sending out the initial* *prototype visors to the NHS was around 3 weeks*." In the Ventilator case, VenMan1 adapted a workshop, which was approved by the US government for the maintenance and repair of night vision goggles, into a production facility for ventilators, which produced 135 ventilators that were distributed to hospitals

In all cases, swiftness and flexibility amplified both the created value and the risk for both the customers and providers. For instance, in the Mask case, MasMan2 reported that a multi-week process was reduced to less than a week. This created value for the MasUser by quickly securing the supply of PPE, helping hospitals, patients, and consequently, the wider community. While at the same time it increased the legal risk exposure for MasMan 2, because the mask was not officially approved: *"let us say a bunch of doctors get COVID and they are wearing our masks, are we going to be in trouble because we made donated masks? It's better than wearing no masks or bandanas, but are they going to come back and sue us?"*

While in the Ventilator case, VenDes required only three weeks to develop the first prototype and a further month and a half for tests, compared to 6–10 years for normal ventilator development and full clinical trials. By Christmas 2020, 500 ventilators had been produced and supplied to hospitals, creating a high level of value for users and patients. Simultaneously, there was an increased risk that hospitals would not order ventilators because the approval for emergency use of the ventilators provided by INVIMA (National Drug and Food Regulatory Agency) required civilian hospitals to declare that they had insufficient ventilators, which may discourage hospitals from ordering. Further, it could be argued that there were increased health risks for users, as the ventilator had only completed laboratory trials and trials on pigs, and first-phase clinical human trials were yet to be approved by the regulatory body.

In the Valve case ValDes leveraged 3D printing flexibility to develop and design 3D-printed valves, such that a snorkeling mask could be converted into an emergency oxygen mask. Then ValDes made the design freely available on the market so that any 3D printer could replicate it. This created value as 3D printers across the globe, in total, converted around 150,000 snorkeling masks, contributing to reducing the market shortages for emergency oxygen masks. However, such an approach also created risk for the hospitals and patients because the valves had not been certified. Some hospitals wanted to ensure compliance: *"we had to tell the hospital that if they wanted to use non-certified equipment, they had to notify the Ministry of Health saying "I am in trouble, I do not have product X, I have to use product Y which has these characteristics but has no certification. Can I have the authorization from you?"* (ValDes). The Health Ministry never gave an answer to any hospital. Therefore, hospitals used the valve at their own risk. Based on the above discussed evidence, we propose the following:

Proposition 5: In newly formed networks, operating under conditions of extreme environmental uncertainty, increasing an actor's physical agility capabilities (swiftness and flexibility) beyond what is needed for exploiting regular market opportunities, can generate additional value for users, but can also heighten the network actors' risk exposure.

This proposition advances our understanding of agility's mixed performance outcomes. While increased swiftness and flexibility can enhance operational capabilities, when these exceed an organization's normative operational parameters, as defined by established processes and business practices, firms may face elevated financial, legal, and reputational risks. This finding extends existing research in two ways. First, it builds upon established work demonstrating positive relationships between agility and performance outcomes (e.g., Vickery, Droge, Setia, & Sambamurthy, 2010; Gligor & Holcomb, 2012; Yusuf et al., 2014). Second, it provides empirical support for recent findings suggesting that agility-performance relationships can be non-linear (Gligor, 2016). Our empirical context demonstrates that firms must carefully evaluate their approaches to achieving enhanced agility, particularly when pursuing capabilities beyond their normalized operational thresholds.

Furthermore, we observed that an extremely turbulent and unpredictable environment, combined with pressure to act swiftly, required network actors to change how they behaved in response to this stimulus. In general, firms tend to design and optimize their operating processes and procedures, and how they manage their extended network in a way, to effectively and efficiently exploit their regular market opportunities. However, what we noticed, in our case companies, is a very quick realization by management that established processes and procedures constrained firms in their ability to react swiftly and effectively to the rapidly changing and uncertain environment.

Firms decided to start improvising and acting in a much more entrepreneurial way, which allowed them to be much quicker and more flexible in the execution of their decisions, as captured in the following quote from VisDes, *"…he [Retired Purchasing Director] was probably the best person for the job as we could go to him about his advice and guidance on furloughed staff and money – which was the two things we needed – so he was a sort of blessing in disguise really, because he could make executive decisions about the business on exactly the stuff we needed, and he felt passionately that this was the right thing for us to do – and so we* *could get those decisions made a lot faster than we would typically expect in an organization the size of our company, because we had him on board."*

The emergence of this entrepreneurial behavior was evident from the onset of the crisis and was, for example, manifested in manufacturers' proactiveness in finding alternative sources of supply from suppliers they had never procured before. Next, actors took risks by procuring materials from suppliers that were not prequalified and onboarded following standard supplier evaluation and selection process. New product development processes, for example, were highly improvised because they had to be shortened and much more flexible to accommodate multiple rapid design iterations. MasMan2 illustrated this in the following quote *"We tried nearly 50 different designs. And at that stage we didn't even use computers, just hand drawn sketches. Then we were testing it out, retesting, trying it, and then we found a good best practice sharing it with the team saying "okay guys this group is doing this and they are faster based on our board. Let us look and learn and then try.""* We observed similar behaviors in manufacturing, where firms improvised and innovated with manufacturing process designs, layouts and labor allocation, all in the service of swift and flexible response. VisDes summarized such an approach stating that "*I would probably describe it as being most like a start-up – that was probably what is was most similar to – it definitely felt like we were setting up our own business and running our own little mini-business within the business.*" Our analysis leads to the following proposition:

Proposition 6: In newly formed networks operating under conditions of extreme environmental uncertainty, perceived threat and time pressure, an entrepreneurial orientation in actors' decisiveness, swiftness, and flexibility is essential for creating value for users.

While supply chain agility has traditionally been conceptualized as a firm's capability to respond to sudden changes in customer demand and supply (Gligor and Holcomb, 2012), our understanding of a firm’s responses under conditions of extreme environmental uncertainty, combined with perceived threats and time pressure, remains limited. In this proposition we demonstrate that conventional change practices and processes may be inadequate for effective response in such contexts. Instead, organizational attributes of risk-taking, innovation, and proactiveness emerge as critical determinants that shape actors' decisiveness in decision-making and their subsequent deployment of physical agility capabilities—specifically, operational swiftness and structural flexibility.

Lastly, in Figure 1, we summarize our cross-case analysis and the six propositions in the empirical framework of supply chain agility for extreme uncertainty.

----------------------------- Insert Figure 1 approximately here -----------------------------------

Discussion

The purpose of this research was to uncover how network actors utilize agile capabilities to respond to extreme supply network disruptions within newly formed supply networks. To address this question, we employed a theory elaboration approach with abductive reasoning, drawing on both primary and secondary data from 18 firms in four supply networks. We summarized our findings in six propositions and proposed a process model of agile capabilities in the context of extreme environmental uncertainty. In doing so, we make several key theoretical and practical contributions, which we discuss below.

Theoretical Contributions

In this work, we build on Gligor et al.'s (2013) framework of agile capabilities, which categorizes them into two distinct groups: cognitive capabilities - alertness, accessibility, and decisiveness, and physical capabilities - swiftness and flexibility. Although some scholars have suggested connections between cognitive and physical capabilities, most extant literature still conceptualizes supply chain agility as a second-order reflective construct composed of multiple first-order factors without probing the links among them (Blome et al., 2013; Gligor et al., 2013, 2022; Yang, 2014). Here, we make our first contribution. Our process model of agile capabilities demonstrates that cognitive and physical capabilities, although distinct categories, are closely intertwined. Specifically, increases in swiftness (i.e., the speed of a physical response to external changes) and flexibility (i.e., the scope of tactical and operational modifications) follow from changes in cognitive capabilities. This finding underscores that an effective response to external environmental changes requires the development of both cognitive and physical capabilities. Indeed, focusing solely on physical dimensions is a necessary but insufficient condition for enhancing an actor's, and by extension, the supply network's agility. This observation supports Gligor et al.'s (2013) call for managerial attention not only to physical dimensions but also to cognitive and behavioral aspects of agility.

Moreover, we provide empirical evidence for relationships within the cognitive category—alertness, accessibility, and decisiveness. We show that a network actor's decision-making process (i.e., how resolutely, rapidly, and risk-tolerantly it responds to environmental pressures) arises from the interplay between (1) external uncertainty and (2) actors' alertness and ability to access relevant information. We argue that an actor's alertness should extend beyond sensing shifts in demand to encompass self-awareness (internal awareness), outcomes of current practices, the broader supply network, and the relevant external environment. Our data show that in extreme disruptions, challenges and risks spread across multiple levels of the supply network (Sodhi & Tang, 2021), making a demand-focused approach, advocated by many agility studies, insufficient.

Our empirical model was developed in the context of newly formed supply networks under extreme environmental uncertainty, characterized by substantial, discontinuous change (Sirmon et al., 2007) and a shared perception of an urgent threat (Müller et al., 2023; Raj et al., 2023). Here lies our second major contribution. We posit that effectively responding to such conditions requires firms to develop what we term "extreme agility," which involves the ability of newly formed networks to meet specific, immediate, and time-bound needs (Müller et al., 2023). We further argue that extreme agility is not typically necessary for exploiting regular market opportunities; most business processes and networks are not designed with such urgent demands in mind. Our findings indicate that achieving extreme agility requires network actors to modify how they utilize their agile capabilities. In particular, we refer to the concept of entrepreneurial orientation, a strategic posture characterized by proactiveness, risk-taking, and innovativeness (Covin & Slevin, 1988; Lumpkin & Dess, 1996; Hakala, 2011).

Entrepreneurial orientation has been identified as a critical factor for supply chain hyperagility (Raj et al., 2023) and for facilitating timely responses to immediate needs through ad-hoc supply chains (Müller et al., 2023). We extend network-level discussions by offering deeper granularity, linking entrepreneurial orientation to specific first-order agility capabilities. Our findings show that firms must adapt both their cognitive and physical behaviors—particularly decisiveness, swiftness, and flexibility. Under immense pressure to quickly source personal protective equipment (PPE) and medical supplies, network actors in our cases made proactive decisions to engage with previously unapproved suppliers, despite uncertainties about quality and demand. The urgency also drove them to take risks with limited information on sourcing, product design, manufacturing, and equipment use. Additionally, to boost swiftness and flexibility, firms engaged in high levels of innovativeness, improvising and seeking novel solutions for compressing lead times, developing new products, and managing customer engagement. Hence, we propose that an entrepreneurial orientation—manifested through decisiveness, swiftness, and flexibility, is essential to achieving a faster response than what is typically required in regular market settings.

Beyond these contributions, the extreme uncertainty and time pressures we observed lead us to propose an additional assertion. Although most literature emphasizes the positive impact of agility on firm and supply chain performance (Vickery, Droge, Setia, & Sambamurthy, 2010; Gligor & Holcomb, 2012; Yusuf et al., 2014), including discussions on "ad-hoc" and "hyperagile" supply chains (Müller et al., 2023; Raj et al., 2023, we argue that extreme agility can entail significant risks for network actors. Supporting findings by Skipworth et al. (2022), our research indicates that legal, reputational, and financial hazards can emerge. However, these risks do not inherently stem from greater agility; rather, they arise from the methods firms employ—specifically, the entrepreneurial orientation evident in decisive, swift, and flexible behaviors. These orientations, while crucial for achieving immediate outcomes, may deter some firms from engaging in emergency responses when weighed against potential adverse consequences.

Implications for Practice

This study offers important managerial insights. First, while enhancing physical dimensions of agility, swiftness and flexibility is necessary, it is insufficient for realizing true supply chain agility. Cognitive dimensions such as alertness, accessibility, and decisiveness are not only equally important but also serve as precursors to physical dimensions. Managers should therefore allocate sufficient attention and resources to developing these cognitive capabilities.

Second, in contexts of extreme environmental uncertainty and urgent, specialized demands, firms must heighten their levels of agility by modifying how they employ both cognitive and physical capabilities. Our case studies illustrate that proactive behavior, experimenting with new approaches, fostering innovation, and accepting higher levels of risk can substantially boost an organization's swiftness and flexibility. However, these strategies may also expose firms to reputational, operational, legal, and financial risks. Managers should thus carefully weigh the trade-offs between meeting urgent customer needs and the potential for negative outcomes.

Limitations and Further Research

We extend the literature on supply chain agility by examining 18 firms embedded in four supply networks. Gaining full network-level access proved challenging, and in a few instances we relied on accounts from firms with which we had complete access and on publicly available reports. Another limitation involves achieving theoretical saturation across all topics and propositions.

While theory elaboration involves predetermined constructs and relationships, making it harder to ascertain saturation, our data support the propositions we developed. Still, further validation could fortify our theoretical contributions.

Finally, like most case study research, our work faces the issue of limited generalizability. Future research could employ quantitative methods with larger datasets to verify and extend our propositions. Doing so would enhance the applicability of our findings across a broader range of industries and supply chain contexts.

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Appendix 1:

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Tables

Table I: A comparison of frameworks on supply chain agility

Authors	Theory	Agility drivers (environmental)	Agile capabilities / competences	Agile practices / strategies	Performance indicators
Zhang & Sharifi, 2000, 2007	No specific reference	Changes in: • Marketplace • Competition • Customer requirements • Technology • Social factors • Suppliers • Internal complexity	• Proactiveness • Responsiveness • Competency • Flexibility • Quickness • Focusing on the customer • Partnership	• Relationships with suppliers and competitors • Technology • People • Integration • Innovation • Relationships with customers • IT systems	No specific reference
Swafford *et al.*, 2006	Dynamic capabilities	No specific reference	• Flexibility (and IT support) in each value chain function • Product development • Procurement/ sourcing • Manufacturing • Distribution/logistics • IT integration	No specific reference	• Value chain performance • Competitive business performance
Vázquez-Bustelo *et al.*, 2007	No specific reference	• High dynamism • High hostility/ competition • High complexity • High diversity	No specific reference	• Agile human resources • Agile technologies • Value chain integration • Concurrent engineering • Knowledge management	• Manufacturing strength • Business performance
Blome *et al.*, 2013	RBT; Dynamic capabilities	No specific reference	• Supply-side competence • Demand side competence • Process compliance (mediator)	• Adapt to customer requirements • React to market developments • Adjust product portfolio • React to supply changes	• Operational Performance (customer service, cost, service level, flexibility)
Gligor & Holcomb, 2012; Gligor *et al.*, 2013; Gligor, 2016	RBT; Dynamic capabilities	• Environmental dynamism • Environmental complexity • Environmental munificence	• Alertness • Accessibility • Decisiveness • Swiftness • Flexibility	• Inventory • Product design • Supplier selection	• Operational performance • Relational performance • Financial performance (ROA)

Table II: Reliability and validity measures utilized in this study

Reliability and validity measures	Research phase			
	Research Design	**Case selection**	**Data collection**	**Data analysis**
Reliability – transparency of case research execution and replication (Yin, 2009)	• Development of research protocol. • Development of case study database, for all four case networks, where we maintained a depository of case transcripts, secondary data, and audio-video materials from case site visits.	• Clear and well documented case selection criteria and case selection process.	• Reporting of semi-structured interview guidelines. • All interviews transcribed by the research team.	• Rigor in coding process and interpretation of results.
Internal validity – building plausible relationships between constructs (Yin, 2009).	• Development of the research framework from literature on supply chain agility and networks.	• Not applicable	• Selection of knowledgeable participants • Multiple participants	• Pattern matching and identification of commonalities between interview quotes, codes, and the extant theory. • Building explanations for within and cross-case comparisons. • Identification of common themes and the mergence of new constructs and relationships, which were formally captured in a set of propositions and the empirical framework in the cross-case analysis.
Construct validity – correct conceptualization and operationalization of the relevant constructs (Jick, 1979, Yin, 2009)	• Grounding of the research protocol in the relevant literature on agility, supply networks and the context of extreme uncertainty.	• Not applicable	• Multiple sources of information – combining primary (semi-structured interviews) and secondary data (videos, photos, company reports, news reports, product descriptions and site visits). • Assured anonymity of all participants.	• Establishment of chain of evidence – starting with the objectives of the research, its theoretical framing, development of research protocol, to the case-study database, data analysis and coding to within-case reports. • Case study reports verified by case participants.
External validity – generalization of research findings, and their applicability to different populations or contexts (Yin, 2009)	• Use of replication logic in multiple case studies	• Selection of the four cases based on pre-developed case selection criteria, grounded in the existing literature.	• Gathering the data on the case context	• Consideration of the case context • Primary concern - pattern matching over statistical generalization.

Sources: Jick (1979), Gibbert et al. (2008), Yin (2009)

Table III: Case studies overview

Cases		Case firms				Interviewees	
				Primary industry of network actors			
	Country	Firm role	Firm code	Healthcare	Non-healthcare	Area of responsibility	No. of interviews
Case 1: Masks Network	USA	Mask User	(MasUser)	Healthcare provider		Supply chain, operations and sourcing	4
		Mask Manufacturer 1	(MasMan1)		Apparel Shoe manufacturer	New product design, operations and commercial	2
		Mask Manufacturer 2	(MasMan2)		Printing	New product design, operations and commercial	2
Case 2: Valves Network	Italy	Valves User	(ValUser)	Healthcare provider		Finance and Purchasing	2
		Valve Designer	(ValDes)		Research and Development	New product design, operations and commercial	2
		Valve Molding Manufacturer	(ValMold)		Plastic Molding	Sales	1
		Valve 3D Manufacturer	(Val3D)		Innovation-3D printing	Engineering and Operations	1
Case 3: Visors Network	UK	Visor User	(VisUser)	Healthcare provider		Purchasing	2
		Visor Designer Assembler	(VisDes)		Automotive	Commercial, Purchasing and New product design	4
		Visor Molding Manufacturer	(VisMold)		Injection molding	Operations	Data collected from interviews with other network actors and combined with secondary data.
		Visor Cutting Manufacturer	(VisCut)		Manufacturing	Operations	Data collected from interviews with other network actors and combined with secondary data.
Case 4: Ventilator Network	Colombia	Ventilator Military User	(VenUser2)	Healthcare provider		Purchasing	1
		Ventilator Civilian User	(VentUser1)	Healthcare provider		Purchasing	Data collected from interviews with other network actors and combined with secondary data.
		Ventilator Designer	(VenDes)		Education and Research	Commercial and New product design	2
		Ventilator Tester	(VenTest)		Research and Development	Engineering, Sales and Logistics	2
		Ventilator Manufacturer 1	(VenMan1)		Defense manufacturing	Operations and supply chain	1
		Ventilator Manufacturer 2	(VenMan2)		Home appliances manufacturing	Operations	Data collected from interviews with other network actors and combined with secondary data.

		Ventilator Part Manufacturer	(VenPart)		Industrial equipment manufacturer	Operations	Data collected from interviews with other network actors and combined with secondary data.
						Total no. of interviews	26

Table IV: Within-case displays

NETWORK ORGANIZATIONS

Mask

	Mask User	**Mask Manufacturer 1**	**Mask Manufacturer 2**
Agile cognitive capabilities	**Alertness:** Supply chain team highly alert due to PPE shortages and during the new supplier engagement period. **Accessibility:** Had access to new information by combining informal and formal channels. **Decisiveness:** High level of eagerness to find alternative suppliers of PPE.	**Alertness:** Early awareness of health crisis and PPE shortage in local hospitals. **Accessibility:** Had to rapidly find new suppliers for healthcare certified materials **Decisiveness:** Quickly and resolutely engaged in PPE supply and consequent process of developing and manufacturing of face masks.	**Alertness:** Increased alertness to the news of PPE shortage and awareness of resources and constraints to engage in crisis response. **Accessibility:** Had access to product requirements and supporting information facilitated by MasUser. **Decisiveness:** High level of willingness to respond to health crisis. Throughout the entire process of face shield development and manufacturing, decisions have been made very quickly.
Agile physical capabilities	**Swiftness:** Speed of decisions to engage with new suppliers and become involved in product development and coordination significantly increased. A process that would normally last several months lasted one week. **Flexibility:** Changed practices of working and engaging with new suppliers and accommodating newly developed PPE.	**Swiftness:** Design to manufacture time of face mask lasted six days, with extra three weeks to ramp-up manufacturing volumes. **Flexibility:** Could manufacture face masks on shoes production line with simple modifications and adjustments.	**Swiftness:** Increased speed of NPD and manufacturing process. Multi-week process speeded up to less than a week. **Flexibility:** Changed NPD process, re-purposing of manufacturing equipment and new-skilling of workers allowed shift from printing and sign making to face-shield manufacturing.
Outcomes	**Value creation for the user:** Securing supply of PPE. Reduction of risk of disruption to healthcare provision. **Risk exposure:** Increase in legal risk. Increase in product quality risk.	**Value creation for the user:** Securing supply of PPE for MasUser, helping hospitals and consequently wider community. **Risk exposure:** Increase in legal risk.	**Value creation for the user:** Securing supply of PPE for MasUser, helping hospitals and consequently wider community. **Risk exposure:** Increase in legal risk.
Entrepreneurial orientation	Develop new supply sources and reduce of risk of disruption to healthcare provision.	Re-deploy resources during the drop in demand for regular business. Exploit its agile capabilities beyond usual boundaries.	Re-deploy resources during the drop in demand for regular business.

Valve

	Valve Designer	**Valve User**	**Valve Molding Manufacturer**	**Valve 3D Manufacturer**
Agile cognitive capabilities	**Alertness**: After initial demand spike, they checked availability, and found a very critical situation. **Accessibility**: Early exposure due to location. Direct access to clinical data was a key to understand the emergency and act effectively.	**Alertness**: Alerted by a doctor with the support of a hospital. Conducted quick market search to identify need and check snorkeling masks availability. **Accessibility**: Relevant knowledge was accessible due to earlier project. Altruism allowed contributions from all the players.	**Alertness**: Quick early assessment of the pandemic impact, with factories located in the epicenter of the pandemic. **Accessibility**: Using existing capabilities, developed activities based on partner specifications.	**Alertness**: Early access to knowledge thanks to cooperation with Valve Designer and hospitals. **Accessibility**: Access to relevant data on the needs of the hospitals, thanks to a reputation effect. **Decisiveness**: Established early link to leading hospital. Originally engaged to

		Decisiveness: After supply chain disruption, alternative plan emerged, leveraging 3D printing.	**Decisiveness**: Thanks to their expertise in product development, valve development and mask adaptation took eight hours plus three days of testing.	**Decisiveness**: Immediately committed expertise to develop and mass produce ventilator valves.	act as a linking point with local 3D printers, when need for masks evaporated, redirected efforts.
	Agile physical capabilities	**Swiftness**: Immediately started experimenting with 3D printing and sought complementary expertise and production capacity. **Flexibility**: Ready to implement alternative scenarios based on the evolution of the pandemic.	**Swiftness**: Upscaling decision to make design available online was swift. Risks were considered and monitored. **Flexibility**: Original forecast was 100-150 masks to be produced internally. Made the valve design freely available to allow everyone with a 3D printer to manufacture it. Around 150,000 valves produced globally.	**Swiftness**: Swiftly implemented the industrialization and started the production. Managed distribution to hospitals using existing logistics capabilities. **Flexibility**: Set an "emergency committee" meeting twice a day to assess the impact of the pandemic on absenteeism and material shortages.	**Swiftness**: Existing agile capabilities allowed swift implementation of several 3D printing projects Covid related. **Flexibility:** Originally engaged to act as a linking point with local 3D printers Leveraged 3D printing flexibility, developing medical components including a wrapper for filters in using snorkeling mask as PPE.
	Outcomes	**Value creation for the user:** Availability of key components to face market shortages. **Risk exposure:** High risk of using uncertified devices managed by limiting for emergency and under a patient disclaimer.	**Value creation for the user:** Successful development of valve to transform a snorkeling mask into an oxygen mask. **Risk exposure:** Risk managed through clinical tests and legal disclaimers.	**Value creation for the user:** Production and shipments of oxygen valves on a large scale. **Risk exposure:** Provide for free uncertified devices under a disclaimer.	**Value creation for the user:** Address market shortages leveraging on their expertise and on local 3D printer networks. **Risk exposure:** Develop components for medical applications.
	Entrepreneurial orientation	Develop the hospital as knowledge center for a patient-centered innovation Manage the high risk of using uncertified devices by limiting for emergency and under a patient disclaimer.	Upscale project making the valve design available open source, achieving a strong impact globally. Manage risk through clinical tests and legal disclaimers.	Re-deploy in a *pro bono* format its business expertise on molding plastic components. Manage risk by provide for free uncertified devices under a disclaimer.	Develop new business model in clinical engineering to promote high-tech "craftsmanship". Manage risk by certification approach and constrained scope.
Visor		**Visor User**	**Visor Designer Assembler**	**Visor Cutting Manufacturer**	**Visor Molding Manufacturer**
	Agile cognitive capabilities	**Alertness:** Employees aware of and influenced VisDes's decision to manufacture visors. **Accessibility:** Had access to visor data through involvement in visor development and testing. **Decisiveness:** Early involvement in visor development supports the hospitals' resoluteness to purchase it.	**Alertness:** Director liaised with government to coordinate Covid-19 related activities. Visr production triggered by VisDes employees whose family members worked in a hospital with insufficient PPE. **Accessibility**: Visor met the health and safety CE certification. Design and materials were tested. Developed a business case for moving from 3D printing to injection molding. **Decisiveness:** Decided to make a visor rather than other PPE due to demand, and because it was a goof fit with capabilities.	**Alertness:** Detected the opportunity to supply VisDes quickly as an existing 1st tier supplier. **Accessibility**: Were able to use the Computer Aided Designs immediately. **Decisiveness:** Quickly and resolutely offered their services for cutting the visor.	**Alertness:** Aware early of VisDes's need to switch from 3D printing to injection molding through senior level contacts. **Accessibility**: Had access to CAD drawing for injection molding. **Decisiveness:** Quickly and resolutely offered their services (purchased steel for mold before commitment from VisDes)**.**

	Agile physical capabilities	**Swiftness:** Quickly decided to get involved with the design of the visor. **Flexibility:** Changed PPE practices to use the reusable visor and this gave the hospital flexibility to meet surges in PPE demand.	**Swiftness:** From initial request to delivering prototype visors to hospitals was around three weeks. 3D printed the headband initially to speed up visor development.	**Swiftness:** Quickly cut sample and final design visors and returned to VisDes. **Flexibility:** Global shortage of visor polycarbonate material meant VisCut needed to adjust their production schedules.	**Swiftness:** Simple headband design to ensure fast manufacture of injection mold. From VisDes sending the design to production of headband in around 10 days. **Flexibility:** Modified tools to give VisDes what they needed.
	Outcomes	**Value creation for the user:** Visor used to manage surges in PPE demand in critical care and high usage areas.	**Value creation for the user:** Develop visor components which are simple and easy to clean enabling it to be reused. **Risk exposure:** Multiple variants of the visor created complexity and risks for product labeling and tracing.	**Value creation for the user:** Provided a quick visor cutting service to VisDes responding to increasing demand quickly.	**Value creation for the user:** Provided VisDes with molded headbands quickly. Later quadrupled their rate of production and established an assembly line in response to increases in demand.
	Entrepreneurial orientation		Unlock resources become available because of the drop in demand for cars.	Set up a quick visor cutting service.	Follow demand trend, quadrupling their rate of production and establishing an assembly line. Stop the production when demand dropped.
Ventilator		**Ventilator Civilian User**	**Ventilator Military User**	**Ventilator Designer**	**Ventilator Tester distrib+ after sales service**	**Ventilator Military Manufacturer**
	Agile cognitive capabilities	**Alertness:** Detected threat of insufficient commercial ventilator supply. **Accessibility:** Accessed information on prototype ventilator supply. **Decisiveness:** Resolutely decided to acquire and use the ventilator when insufficient ventilators available.	**Alertness:** Detected need for more ventilators. **Accessibility:** Accessed information on prototype ventilator design and supply. **Decisiveness:** Resolutely decided to participate in ventilator design and use it.	**Alertness:** Detected need for more ventilators before the pandemic reached Colombia by observing the shortages in the rest of the world. **Accessibility**: Relevant data was easily accessed on ventilator designs and supplier capabilities enabling swift acquisition. **Decisiveness:** Resolutely decided on ventilator design and supplier selection, e.g. open source MIT (USA) ventilator design was resolutely rejected because of difficulties assuring the precise volumes of air/pressure needed to avoid lung injury.	**Alertness:** Detect need for ventilators maintenance and repair at hospitals. **Accessibility**: Accessed relevant data on tests and equipment. **Decisiveness:** Decided to support Ventilator Designer resolutely and quickly.	**Alertness:** identified the need for mechanical ventilators at the start of the pandemic. **Accessibility**: Visited military hospitals to understand more about the needs of Covid-19 patients. **Decisiveness:** Sometimes management doesn't prioritize R&D, but there was a focus on pandemic response, so senior management convened meetings dedicated to finding solutions to R&D problems.
	Agile physical capabilities	**Swiftness:** Quickly acquired ventilator**.**	**Swiftness:** Responsively participated in ventilator design and acquired it.	**Swiftness:** Only three weeks required to develop the first prototype and a further month and a half for tests, compared	**Swiftness:** The laboratory lung simulator tests and tests on pigs were conducted over about two	**Swiftness:** Learned about 'express' product development. Normally need up to three years to develop a military product,

		Flexibility: Modified operations to use the prototype ventilator.	**Flexibility:** Modified operations to use the prototype ventilator.	to 6–10 years for normal ventilator development and full clinical trials. **Flexibility:** Operations around prototype development and testing were modified using the resources of the schools of medicine, engineering and management.	months, which would normally take years. **Flexibility:** Modified operation to support the wide range of tests and trials required.	but the commercial ventilator was developed in 2-3 months. **Flexibility:** Adapted a workshop for night vision goggles manufacture into a production facility for ventilators.
	Outcomes	**Value creation for the user:** Securing supply of ventilators for critically ill patients where insufficient commercial ventilators available. **Risk exposure:** Increase risk to patients that the ventilator may not work properly or may cause damage since human trials are not completed.	**Value creation for the user:** Securing supply of ventilators for critically ill patients. **Risk exposure:** Increase risk to patients that the ventilator may not work properly or may cause damage since human trials are not completed.	**Value creation for the user:** By Christmas 2020 500 ventilators had been produced and supplied to hospitals. **Risk exposure:** Face the risk of failing to assure the precise volumes of air/pressure needed to avoid lung injury.	**Value creation for the user:** Engineering tests, laboratory lung simulation tests and tests on pigs successfully completed.	**Value creation for the user:** Produced 135 ventilators that were distributed to hospitals.
	Entrepreneurial orientation	Decide to acquire and use the ventilator when insufficient ventilators available.	Decided to participate in ventilator design and use it.	Design the ventilator and select the supplier been fully aware of technical limitations (e.g. the difficulties of assuring the precise volumes of air/pressure needed to avoid lung injury).		Focus senior management on finding solutions to R&D problems.

FIGURES

Figure 1: Process framework of supply chain agility for extreme uncertainty