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# Supply Networks for Extreme Uncertainty:

# A Resource Orchestration Perspective

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## ABSTRACT

**Purpose:** Disasters are growing in frequency and scale, unmasking the systemic vulnerabilities of modern supply chains and highlighting the need to understand how to respond to such events. In the context of an extreme event such as the Covid-19 pandemic, this research focuses on how networks of organizations leverage their combined resources and capabilities to develop, manufacture, and deliver new products outside their traditional markets.

**Design/methodology/approach:** Following a theory elaboration process, we build on resource orchestration theory to develop data collection and analysis protocols to support a multi-case study research design. This research investigates four cases of newly formed networks that emerged in four different countries – Colombia, Italy, the United States, and the United Kingdom – in response to the Covid-19 pandemic.

**Findings:** These four networks in our investigation share common characteristics in terms of motivation and approach, creating patterns from which theoretical generalizations are developed into a series of propositions regarding the process of network-level resource orchestration under extreme uncertainty.

**Originality:** This research contributes to theory by extending the resource orchestration model to a network level and showing how extreme uncertainty can lead to the emergence of networks and alter the motivations and goals of the member organizations, allowing them to be more responsive.

**Practical implications:** The research shows how networks and the organizations within them can streamline processes, swiftly build new relationships, and develop a balanced risk management approach to extreme uncertainty.

**Keywords:** Resource Orchestration, Networks, Crisis Management, Case Study Research

**Article classification:** Research paper

## INTRODUCTION

Natural and human-made disasters are constant calamities that afflict millions of people, and there is mounting evidence that these incidents are growing in frequency and scale (Gupta et al., 2016). This worrying trend has attracted the attention of practitioners and researchers to devise ways to avoid, mitigate, respond to, and recover from disasters. For this reason, research into topics of resilience and business continuity has grown over the last few decades (e.g., Brandon-Jones et al., 2014; Quarshie & Leuschener, 2020; Azadegan & Dooley, 2021). However, the extreme conditions associated with the Covid-19 pandemic go beyond a supply chain risk affecting a limited number of organizations for a short period (Sodhi & Tang, 2021). The pandemic has unmasked the systemic vulnerabilities of modern supply chains, highlighting the need to explore how organizations respond to extreme events (Flynn et al., 2021).

The Covid-19 pandemic has affected practically every organization on Earth, both directly, through the devastating effects of the disease, and indirectly through travel bans, lockdowns, social distancing, and disruptions to the supply of goods (Sodhi & Tang, 2021). In response to these challenges, organizations quickly sprang into action, trying to both survive and support their communities. As a result, we witnessed the emergence of new networks of organizations that leverage their combined resources and capabilities to swiftly develop, manufacture, and deliver new products outside their traditional markets, often without a direct profit motivation. Aerospace firms producing face masks, automotive firms producing ventilators, and breweries producing hand sanitizers, are just some of the examples (Urquhart, 2021).

In this paper, we build on resource orchestration (Sirmon et al., 2007; 2011; Sirmon & Hitt, 2009) to help understand how networks of organizations sprang into action to respond to the Covid-19 pandemic. We seek to extend the theory by using the constructs and relationships and

expanding their boundary conditions by applying them in the context of newly formed supply networks. In doing so, we intend to unveil changes in practices that have been instigated by the Covid-19 pandemic, as suggested by Micheli et al. (2021). To do so we follow a theory elaboration process where extant theory is used to inform data collection and analysis (Ketokivi & Choi, 2014). Specifically, we ask: *How do supply networks orchestrate resources to respond to extreme uncertainty?*

We use a multi-case study research design consisting of four cases of newly formed networks that emerged in response to the Covid-19 pandemic. All four networks were created by organizations that volunteered their resources and capabilities to develop, manufacture and distribute new products that were needed, such as personal protective equipment (PPE) and ventilators. While the four networks operate in different countries – Colombia, Italy, the USA, and the UK – they all share common characteristics in terms of motivation and approach, creating patterns from which we develop theoretical generalizations. These theoretical generalizations are encapsulated into eight research propositions regarding the process of resource orchestration across a network under extreme uncertainty.

Our research contributes to theory by extending the resource orchestration model to a network level. We reveal how extreme uncertainty and a shared sense of threat can alter the motivations and goals of organizations engaging in network-level resource orchestration, allowing them to be more responsive. Our research also unveils the tactics deployed by network actors to accelerate resource orchestration cycle time during a crisis, namely: circumventing, resource unlocking and refocusing, and swift relationship building. Further, our research elaborates on resource orchestration theory by showing alternative outputs of the orchestration process. In contrast with Sirmon et al. (2007), who propose firm-level competitive advantage as

the main output of resource orchestration, this research identifies three alternative network-level outputs: the creation of value for network beneficiaries, the advent of goodwill for network actors, and the emergence of risks for these actors. Finally, our model considers the impact of risk stemming from resource orchestration and how this alters future resource orchestration efforts. From a practical perspective, the research shows how organizations can swiftly streamline their processes and develop new partnerships in response to extreme uncertainty, and highlights the need for a balanced risk management approach.

Following this introduction, we review the theoretical background, discussing the literature on resource orchestration. We then present the methodology, describing our approach to case selection, data collection and analysis. This is followed by the cross-case analysis sections, where we present our theoretical elaboration and propositions. Finally, we discuss the contributions and limitations of the research.

Kovács and Tatham (2009) examined, from a conceptual perspective, the phenomenon of resource configuration in humanitarian and military organizations to determine how they spring into action to respond to a disruption. In a subsequent paper, Tatham and Kovács (2010) describe how networks or humanitarian organizations are hastily formed in response to rapid-onset disasters. Yet, they acknowledge the need for further research into the mobilization of resources in the transition from dormant to action in the event of a disaster (Kovács and Tatham, 2009).

## THEORETICAL BACKGROUND

This section discusses the theoretical underpinnings of our work, which are presented in three subsections. First, we review the literature on supply chain management in extreme conditions, with a specific reference to the Covid-19 response. Then we focus on resource orchestration

theory and articulate how the dynamic management of resources across networks of organizations can help respond to the pandemic. We then discuss the resource orchestration process, articulating how the different stages can help organizations cope with environmental uncertainty. Finally, we discuss the value of extending the resource orchestration theory to a network level to understand how networks can leverage their collective resources and capabilities to articulate a response to disasters.

**Supply Chain Management in Extreme Conditions**

Extreme conditions can be defined as those conditions that "go beyond a supply chain risk incident affecting a limited number of companies for a short period … [and] disrupt supply chains along multiple dimensions simultaneously" (Sodhi & Tang, 2021, p.8). Under such conditions, being a response to a pandemic, like Covid-19, a natural disaster or a warfare scenario, the key issue is how organizations are able to spring into action (Kovács & Tatham, 2009).

An effective supply chain response finds its first challenge in the lack of visibility as organizations have to deal with short-term unavailability of supplies, quality issues and demand-related uncertainties (Sodhi & Tang, 2021). Organizations have to be able to manage ambiguity as they are operating in a context where there is a lack of clarity and consistency (Gunessee & Subramanian, 2020). They have to accept a decision-making process that, while built upon a preliminary preparation phase, cannot wait to act till when a "completely right" plan has been designed (Kovács & Falagara Sigala, 2021) and that is able to deal with informal relational governance, going beyond contractual elements (Azadegan at al., 2020).

While buffering and bridging with existing suppliers can be effective actions to face supply chain disruptions, an increase in the magnitude of the adversity will urge an organization "about questioning existing behaviors, rules, strategies, or structures" (Bode et al., 2011, p. 836). The "traditional" supply chain risk approaches, leveraging on prepared responses and on existing supply networks, might not be able to cope with extreme conditions disruptions (Sodhi & Tang, 2021). In most cases, the response to extreme disruptions has to go beyond a demand-supply rebalance and calls for a bottom-up, problem-based innovation (Ardito et al., 2021). It often involves the repurposing of technologies, processes and resources for uses that they were not initially designed for (Ardito et al., 2021) and it leverages on open collaboration across all the players, including public actors and even competitors (Di Minin et al., 2021).

Even if suppliers might be relatively immobile and supply chain assets relatively fixed, when the perceived intensity of institutional pressure and the perceived severity of the potential disruption risks are high, supply chain executives need to adopt a new logic in their design and management of the supply network (Roscoe et al., 2022). Large firms might have to radically rethink their way of operating, building up ad-hoc project supply chains and embedding an entrepreneurial approach in their supply chain design and practices (Ketchen and Craighead, 2021).

**Resource Orchestration Theory**

Resource orchestration theory is an extension of the resource-based view (Wernerfelt, 1984; Barney, 1991), which incorporates the development of dynamic capabilities and external resources, and acknowledges the critical role of managers (Helfat, 2007; Sirmon et al., 2007, 2011). The central argument of resource orchestration is that managerial action is necessary to

structure, bundle, and leverage resources and capabilities to create value (Sirmon et al., 2007). Sirmon et al. (2007; 2011) propose a sequential model of resource orchestration involving three main stages: (1) structuring the resource portfolio, (2) bundling resources to build capabilities, and (3) leveraging capabilities. Sirmon et al. (2007) propose that each of these three stages comprises sub-processes covering different aspects of resource orchestration. Table 1 presents definitions of each of the stages and their sub-processes.

All stages and sub-processes in the resource orchestration model are contingent on the environment, including factors such as instability of supply and demand, probability of environmental shocks, and the degree of environmental munificence (i.e., the abundance or scarcity of critical resources) (Sirmon et al., 2007). Therefore, managers need to adjust the resource management process at every stage of the resource orchestration process in relation to environmental uncertainty (Sirmon et al., 2007). Thus, conditions of extreme environmental uncertainty, where change is substantial and discontinuous, require entrepreneurial approaches to rapidly mobilize and integrate capabilities into new configurations (Sirmon et al., 2007). Table 1 also describes how environmental uncertainty can affect the process.

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Resource orchestration addresses the concerns about the resource-based view, such as being static, insular, tautological, and limited in prescriptive value and applicability (e.g., Sirmon et al., 2007; Kraaijenbrink, Spender & Groen, 2010; Bromiley and Rau, 2016) by considering external resources and environmental contingencies, incorporating dynamic capabilities, and proposing a process for structuring, bundling and leveraging resources and capabilities (Sirmon et al., 2007).

Incorporating environmental contingencies is particularly valuable for investigating resource orchestration processes under extreme uncertainty.

While resource orchestration theory is grounded in the strategic management literature, authors have increasingly advocated for its relevance in the supply chain context (e.g., Hitt, 2011). Yet some argue that the theory remains underexplored within supply chain research (Craighead, Ketchen and Darby, 2020). Thus far, the theory has been applied to operations and supply chain challenges such as integration (Liu et al., 2016; Smals et al., 2020), performance management (Koufteros, Verghese & Lucianetti, 2014), sustainability (Gong et al., 2018; Wong, Wong & Boon-itt, 2018), product recalls (Ketchen et al., 2014) transparency/traceability (Gligor et al., 2022; Malik et al., 2021), supply chain flexibility (Burin et al. 2020), and supply chain resilience (Brandon-Jones et al., 2014; Chunsheng et al., 2020; Queiroz et al. 2022).

The original conceptualization of resource orchestration focused on how a firm structures, bundles and leverages its resources to achieve a competitive advantage (Sirmon et al., 2007). However, as Fawcett et al. (2022) explain, even within the firm organizational boundaries (structural and psychological) hinder managers' efforts to identify, access and uniquely configure these assets to create unique value. Breadth refers to orchestration across these boundaries within the firm and is determined by three moderating factors, including extent of market diversification, which increases the range of resources needed to synchronize efforts and may lead to managers using different supplier and customer bases, as shown in our study.
Further, as the theory has evolved, it has become clear that the orchestration process extends beyond a single firm (Craighead et al., 2020; Hitt, 2011; Liu et al., 2016; Fawcett et al., 2022). Fawcett et al. (2022) explain that this extension to an interorganizational perspective is analogous to the relational view's extension of classic Resource Based View theory. As Hitt

(2011: 10) acknowledges, "*... When the suppliers are external to the firm, the resource management process is more complex. In particular, the relationship between the firm and its suppliers is an essential component of managing resource flows. And, the leveraging and bundling of resources obtained from external sources can be challenging. The management of resources and the resource flow from suppliers to the focal firm could benefit from more empirical research…."* Indeed some authors have embraced the challenge presented by Hitt (2011), trying to extend resource orchestration to dyads (e.g., Chunsheng et al., 2020; Gligor et al., 2022; Liu et al., 2016; Smals et al., 2020); and supply chains (e.g., Brandon-Jones et al., 2014; Gong et al., 2018; Koufteros et al., 2014; Ketchen et al., 2014). However, empirical research into resource orchestration at a network level is conspicuous by its absence. In this research, we seek to elaborate on resource orchestration theory by investigating how networks of organizations jointly orchestrate their resources to swiftly respond to an extreme event. Thus, we extend Sirmon's (2007) conceptualization of resource management to define network-level resource management as a process by which network members collaborate to structure the network's resource portfolio, bundle their collective resources to build capabilities, and leverage those capabilities to create value for network actors.

Resource orchestration theory can help our understanding of network-level responses to extreme uncertainty for several reasons. First, the theory focuses on how resources and capabilities can enable value creation for individual firms (Sirmon et al., 2007). Second, the theory emphasizes the contingent role of environmental uncertainty in the effectiveness of value creation from resources (e.g., Sirmon et al., 2007). Finally, as the theory expands from its initial firm-level boundaries to incorporate the role of resources external to the firm, it opens

opportunities to investigate how networks of organizations can collectively orchestrate their resources for the benefit of their communities.

Resource orchestration theory also has distinctive features that make it suitable for the study of disaster situations, as it can bring precision into the process of structuring, bundling, and leveraging resources to respond to disasters (Craighead, Ketchen & Darby, 2020). However, Craighead, Ketchen & Darby (2020) note that, in contrast to traditional applications of resource orchestration theory where organizations focus on their own competitive advantage, during a disaster, organizations orchestrate resources to create value for society (Barney, 1991). Thus, in this research, we do not focus on individual organizations and their performance; but on networks and how they can respond to disasters.

## METHODOLOGY

In this research, we aim to uncover how networks of actors brought their resources and capabilities together to orchestrate a response to the Covid-19 pandemic. We focus on theory elaboration with abductive reasoning, using a multi-case study approach (Niiniluoto, 1999; Yin, 2009; Ketokivi and Choi, 2014). The case study approach lends itself well to situations when used for exploring novel questions of how and why types, when researchers examine concepts in terms of their meaning and interpretation in a specific inquiry (Edmondson & McManus, 2007; Yin, 2009; Denzin & Lincoln, 2011) or, as in the case of theory elaboration, when one is aiming to introduce new concepts, investigate in-depth relationships among concepts, or examine boundary conditions of a theory in a new context (Whetten, 1989; Fisher & Aguinis, 2017). In this work, we use an emerging theory of resource orchestration by Sirmon et al. (2007, 2011), which we aim to refine by applying it to a new context of extreme environmental uncertainty and

organizational embeddedness in a new context of extreme environmental uncertainty and organizational embeddedness in wider supply network. To do this, we follow the four-step abduction approach proposed by Sætre and Van de Ven (2021):

- Step 1: *Observe the anomaly* through cognitive attention, experience and both, practical and theoretical knowledge. In the case of our work, the observed anomaly was the emergence of previously non-existing supply networks and a dramatic increase in speed and flexibility of responding to extreme uncertainty – i.e. global health crisis caused by the Covid-19 outbreak.
- Step 2: *Confirm the anomaly* through diagnosing key characteristics (confirmation from up close) and the context (confirmation from afar) in which it unfolds, which the authors have done through preliminary gathering of newspaper reports, academic literature and conversations with practicing managers who have been involved in responding to Covid-19 pandemic, which has resulted in the confirmation of the existence of the observed anomaly and identification of the resource management as one of the critical factors.
- *Step 3: Generate hunches and ideas* that may explain the anomaly. This step requires insights generated from the early analysis of the primary and secondary data, which the research team has collected from the case companies and detailed in the continuation of this section.
- *Step 4: Evaluate hunches* – and agree on the most plausible explanations for the subsequent theory construction, which has been done through a systematic combining and cycling between the theory and data to develop a set of propositions that explain how network actors orchestrated their resources and capabilities, to respond to the Covid-19 pandemic.

Next, we explain our approach to case sampling, data collection and analysis, yielding insights to move through Steps 3 and 4 of Sætre and Van de Ven's (2021) approach.

**Case Sampling**

To select our cases, we followed replication sampling as recommended by Eisenhardt (1989), Meredith (1998) and Patton (2002). As part of this process, we first developed, based on literature, a set of case selection criteria, which have been further refined as we engaged with empirical observations of how organizations responded to extreme uncertainty. This approach is in line with Dubois and Gadde's (2014) suggestion that in abductive approaches, researchers should pay attention to accommodating empirical observations with decisions related to case selection, given that the 'boundaries' of case selection may change during the research process. The final case selection criteria were the following:

- *Non-traditional healthcare supply networks:* To combat disruption in PPE and medical equipment through regular supply channels (i.e., pre-approved and on-boarded healthcare suppliers), hospitals began looking for alternative sources. We gathered, through media reports and conversations with hospital supply chain teams, that alternative supplies of PPE were sought and found in sectors outside of healthcare supply networks. These newly emerged non-traditional healthcare networks offered a unique opportunity for resource and capability management in response to Covid-19-induced environmental uncertainty.
- *Network completeness:* As shown by Choi and Wu (2009) and Choi et al. (2011), from a structural perspective, a network consists of a minimum of three actors – i.e., a triad, which is the smallest unit of a network. Following this, each selected case had to involve

a buyer of PPE/medical equipment (i.e., a hospital) and a network of key suppliers involved in PPE/equipment design, manufacturing and/or distribution. We allowed for design/manufacturing/distribution to be performed by a single supplier or a network of suppliers. We posit that an actor's role in a network is independent of the resource orchestration processes, allowing for variability in actors' network roles, which in turn better reflected a variety of network structures that emerged as a response to extreme environmental uncertainty. To study the newly emerged supply networks, actors involved in PPE manufacturing / design / distribution could not have any prior relationship with the buyer of PPE or be a supplier to other healthcare buyers or be a part of an existing healthcare supply network.

- *Extreme environmental uncertainty:* Each selected case had to operate in conditions of extreme environmental uncertainty, which is caused by a substantial and discontinuous change in elements such as industry structure, market supply/demand volatility and environmental shocks (Sirmon et al., 2007). As shown by Sodhi and Tang (2021), Covid-19 led many companies into a situation of extreme uncertainty due to the sharp increases in demand and a simultaneous sharp decline in supply. This was certainly the case for PPE and some medical equipment. However, some countries and organizations were impacted more than others. Accordingly, each case had to be selected in a geographical area of a major Covid-19 outbreak where buyers (i.e., hospitals) experienced a simultaneous increase in demand for PPE/medical equipment while regular supply was disrupted, and causing potential interruptions to healthcare provision if alternative suppliers could not be found.

The identification of case networks began with the simultaneous identification of geographies and networks that would comply with the case selection criteria. The research team reviewed and monitored publicly available statistics and news reports on the severity of the Covid-19 outbreak (e.g., John Hopkins University and Center for Disease Control and Prevention), as well as industry responses to the PPE/medical equipment supply crisis. This was combined with the research team members' outreach to hospitals or non-traditional healthcare suppliers, which were identified either through media coverage and professional or personal connections. Once these organizations were identified, a short interview with personnel involved in coordinating the response to the Covid-19 outbreak was conducted to briefly introduce the project and assess the alignment of a case network with the case selection criteria. Once the alignment was confirmed, and the management agreed to participate, the research team got introduced to other relevant organizations in the network, and the process of data collection began.

**Data Collection Process**

Each case consisted of a hospital as a user of PPE/medical equipment and a set of non-healthcare sector suppliers involved in the PPE/medical equipment development, manufacturing and/or distribution. The unit of analysis was an individual actor in a network, while the unit of reference was a network of studied actors.

To collect the data, a semi-structured interview protocol was developed. The protocol was divided into three key parts. The first part focused on the Covid-19 outbreak's impact on the organization, its network and the external environment. The second part focused on the organizational-level and network-level response to Covid-19, including resource management

and capability building and deployment in the process of new product development, manufacturing, and distribution. The third part focused on the outcomes of the response, key learning points and interview closure.

All interviewees participated in this research on a voluntary basis. Prior to each interview, we sought permission to record the interview to allow verbatim transcribing and data analysis, which was granted to us by all interviewees.

We collected the data from four case networks in the US, Italy, UK and Colombia through 26 interviews with 13 different organizations. Given that studying networks is extremely challenging, particularly with regards to ensuring and maintaining case access to all members of a network, we complemented our primary data with secondary data in two ways: first, we collected data *about* five network organizations where we did not have direct access from primary organizations in their network; and second, we collected information from company reports and media outlets, which helped us to increase both, the completeness and the depth of understanding of the studied phenomena.

The details of the case networks, companies and interviews are captured in Table 2. Each case study is described in detail in Appendix 1.

----------Insert Table 2 Approximately Here----------

Furthermore, and in line with recommendations for conducting rigorous, case-based research, we developed, and employed, a multitude of tactics for ensuring the validity and reliability of this work, which we present in Table 3.

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**Theory matching and data analysis**

Theory elaboration emphasizes abductive reasoning, which involves "*modifying the logic of the general theory in order to reconcile it with contextual idiosyncrasies*" (Ketokivi and Choi, 2014; p. 236). In other words, during data analysis, researchers constantly move between the existing theory and data in an attempt to reaffirm existing constructs, relationships, or sequences between them, but also to introduce new, or split existing constructs, redefine specific relationships between constructs or a sequence of events (Fisher and Aguinis, 2017). This approach allowed us to reaffirm several existing constructs related to resource management and the development of capabilities for response to extreme uncertainty.

Our explanations of how network actors managed their resources and developed capabilities to respond to the crisis emerged after many cycles of theorizing, examining the data from all four case networks, and rethinking the emerging findings (Dubois and Gadde,2002, 2014). The data analysis process began with in vivo coding (Miles, Huberman, & Saldaña, 2014) on verbatim transcripts to gain an understanding of emerging themes in the collected data. In the next stage, open codes were generated on the basis of cycling between the extant theory and emergent themes from the collected data, which allowed for the contextualization of the nascent findings (cf. Gioia, Corley, & Hamilton, 2013). Next, open codes were consolidated in the focused codes. This stage was conducted by four researchers independently to arrive at an inter-rater reliability of 93.5%. Differences were reconciled through dialogue and further examination of data. In the fourth stage, the focused nodes were collapsed into particular nodes through continuous cycling between the findings and the theory. In this way, we identified several constructs and relationships between constructs that we were able to trace back to general theory on resource

orchestration (Sirmon et al., 2007). As part of this process, and in line with abductive reasoning, several new constructs and relationships emerged from the data as well, particularly around the network actors' approaches to resource structuring, resource bundling and outcomes of resource management. The research team conducted a multitude of meetings comparing the emerging findings within and between cases and building explanations for their emergence both on their own and in relation to the constructs and relationships of the general theory.

This study is grounded on responses from multiple participants from 13 different actors across four networks, and particular attention was paid to identifying and resolving differences in opinions. In most instances, the participants were in strong agreement, mainly due to the nature of questions asked, which focused on the management of the resources in response to a crisis, which they were knowledgeable about. To counter the emergence of discrepancies in data interpretation, every interview was coded independently by at least two researchers and then compared for similarities and differences. In the few situations where discrepancies in data interpretation arose, the rest of the team would be involved to reconcile the differences.

## ANALYSIS AND PROPOSITION DEVELOPMENT

As is customary in case study research, we first conducted a within-case analysis followed by a cross-case analysis supporting our theoretical elaboration. In this section, we present both levels of analysis and conclude with a series of propositions. This structure is also in line with the abductive process described by Sætre and Van de Ven (2021) as we observe and confirm the phenomenon of network-level resource orchestration and then generate and evaluate propositions that reflect the orchestration process.

## WITHIN-CASE ANALYSIS

In this sub-section, we briefly describe the four case studies. A more detailed within-case analysis is included in Appendix 1.

### Case 1 – Masks (Mas)

MasUser is a US hospital chain that faced a disruption of PPE supply through their regular supply channels during the surge in demand due to the Covid-19 outbreak. Left with no options, and elevated concerns for the health and wellbeing of hospital staff and patients, they began an intense search for alternative, non-healthcare suppliers of PPE. In parallel, CEOs of two local suppliers, a shoe manufacturer (MasMan1) and a printing and signage company (MasMan2) became aware of the acute PPE shortage and started looking for ways to help. The three firms became connected via informal channels and were quickly onboarded – MasMan2 for the supply of face shields and reusable masks and MasMan1 for disposable and reusable masks. Both suppliers coordinated during the NPD process with MasUser's procurement team, doctors and nurses to rapidly develop prototypes, and then adjust and further refine their manufacturing process. It took three days to develop prototypes and one week to get the first batch of usable products out of their production lines, agility they had not witnessed before.

### Case 2 – Valves (Val)

In March 2020, ValUser hospital faced a surge in Covid cases. Suddenly their regular suppliers were unable to provide oxygen mask valves. ValUser had limited 3D printing experience and contacted ValDes, an R&D company with solid expertise in product development outside the health sector. A retired doctor from ValUser suggested ValDes design a valve that could

transform a snorkeling mask into an emergency oxygen mask. In one day they designed a suitable valve and, after a three-day testing in ValUser hospital, they 3D manufactured and distributed the first 100 units to local hospitals as uncertified products. This process would normally take many months in prototyping and testing. ValDes immediately understood that global demand for such a valve would be so high that they alone would not be able to provide enough valves, therefore they made the design freely available on the web. Many 3D printers – such as Val3D – managed to manufacture these valves, as well as additional customized medical components. In parallel, the snorkeling mask manufacturer (ValMould) supported ValDes to fine-tune the valve, volunteered to industrialize its design and started producing these valves on a large scale. As a result, in the first wave of Covid, around 150,000 valves were produced and made available globally.

**Case 3 – Visors (Vis)**

VisDes is a UK automotive assembler that temporarily ceased operations following the sharp fall in demand at the start of the Covid-19 pandemic. VisDes became aware of the need for more PPE as employees reported that family members working in hospitals were suffering from a severe shortage. A visor was quickly selected and designed within three weeks through trialing at local hospitals. An existing supplier (VisCut) cut the polycarbonate visor, and initially the headband was 3D printed by VisDes (and other organizations with idle 3D printers). VisDes rapidly established an assembly line in a disused building with quality inspection and delivery to local hospitals. As demand increased, it was decided to switch from expensive 3D printing of the headband to injection molding, and VisMould quickly offered their service free of charge. Within ten days of design receipt, they were supplying moldings, compared to several months or

even years it takes to source an automotive component. As demand increased, VisMould took over visor assembly to release VisDes resources for return to automotive assembly.

**Case 4 – Ventilators (Vent)**

A University in Colombia (VenDes) detected the need for more ventilators before the pandemic reached Colombia by observing global shortages. VenDes quickly assembled a multi-disciplinary cross-University team to develop the ventilator and identified Colombian suppliers for the critical components. VenTest was selected to perform laboratory simulations, and trials on pigs and humans and thus closely collaborate with the regulatory bodies. A military factory (VenMan1) and a domestic appliance manufacturer (VenMan2) were identified for volume ventilator manufacture. VenTest provided distribution, installation, clinician training and maintenance/repair services to the hospitals, which included a military hospital (VenUser2) and civilian hospitals (VenUser1). The Colombian Government issued emergency approval for prototype ventilators that had not completed human trials. However, civilian hospitals were required to first declare that they had insufficient commercial ventilators. The ventilator was developed, and preliminary non-human tests were performed, such that it was available to hospitals after just two months, compared to the normal 6-10.

## CROSS-CASE ANALYSIS

### A Common Context: Environmental uncertainty and supply chain disruptions

The Covid-19 pandemic presented network actors with an uncertain environment, particularly in the early days when little was known about the virus. The four cases reveal a conflation of factors leading to the formation of new networks. On the one hand, there was a severe increase

in uncertainty of supply, demand, and labor, which affected normal operations at the organizations involved. In some cases, this uncertainty led to temporary shut-downs. On the other hand, there was a direct threat to the life of employees and members of the community.

All four cases show organizations joining forces, creating new networks around common goals by combining their diverse capabilities such as design, manufacturing, distribution, and patient care. In one of the cases, we revealed how a hospital, a manufacturing company, and a university came together to design, manufacture, and deliver ventilators. In another example, a hospital and 3D manufacturers created a network to manufacture and deliver valves. We found similar altruistic efforts involving multiple organizations across all cases, where the presence of uncertainty and a common threat motivated actors to create new networks to help their communities, suppressing competition and promoting cooperation instead.

The pandemic caused considerable disruptions to supply, demand, and labor availability, creating resource imbalances throughout supply chains. These imbalances, found across all case studies, manifested as shortages (or surpluses) of resources among the network members. However, the implications of these imbalances differed depending on each organization's role. On the demand side, some customers canceled orders, while others requested additional supplies. The consequence of these imbalances was that some functions and organizations, lacked capacity while others had a surplus.

On the supply side, dealing with shortages became the order of the day. Customers were desperate to get orders fulfilled, fueling competition for supplies. One of the most dramatic situations arose at hospitals running short of PPE: "*Once everyone started placing orders, I mean it was a ten-fold situation, we could not get a dime out of them [supplier]*" (MasUser). Upstream in the supply chain, suppliers were also struggling as raw materials became scarce. This meant

that, even when some organizations had the capacity to operate, they could not do so effectively because necessary resources were unavailable elsewhere in the supply chain.

Another resource challenge emerged from staff shortages. One interviewee remarked: "*We had enormous organizational difficulties because we had peaks of absenteeism of over 40% linked to people who were not only sick but also afraid; daily the production schedule was upset…*" (ValMould). However, many of these imbalances were temporary as organizations found ways of keeping personnel occupied by shifting them to other activities. Similarly, organizations tried to address shortages of other resources by linking with new suppliers, finding alternative materials, and essentially restructuring the networks to address the imbalances.

The four case studies took place in different countries and different industries, and yet they were all affected by the same global phenomenon: the Covid-19 pandemic. This phenomenon created an environment of extreme uncertainty, which was perceived as a threat by network participants across the four cases because it created supply and demand disruptions and fostered resource imbalances. These conditions triggered a network-level resource orchestration process, as discussed in the sub-sections that follow.

**Sense of urgency and enhanced speed**

The threats to society posed by the first wave of the pandemic created a sense of urgency that pushed many organizations to become faster, developing, manufacturing, and distributing new Covid-19-related products in a fraction of the normal cycle time, as they felt they had to move with greater speed than in a normal situation, as is well represented in our cases. "*We knew from the very beginning that we would have to develop the ventilator in a few weeks if we wanted to have a ventilator before the peak of the pandemic in Colombia*" (VenDes).

Speed to react to the needs of the community has been recognized in all cases as a key pillar in their Covid-19 response strategy: "*In our opinion speed was the fundamental key. It is not that our project was the best ever in the COVID arena, as I have seen many projects. Our advantage is that we thought about it and eight hours later it was ready*" (ValDes). The speed of reaction translated into swift resource structuring, bundling into capabilities and leveraging of those capabilities in all four cases, as illustrated in this quote from the Ventilator Designer "*We knew that we would have to develop the ventilator in a few weeks and so we only had a few weeks to develop the prototype, have it tested in the laboratory and in the simulation and animal tests … to treat patients for the peak of the pandemic*." (VenDes)

The sense of urgency was such that all actors had to react quickly in a fast-changing environment. *"I have members of my team who … would drive across the country to pick up parts to allow us to have samples and then go and drop that sample off at a hospital to get them to review it and test it for us so we could then start manufacturing them." (*VisDes).

Given the above evidence, we propose:

***Proposition 1a:*** *A strong sense of urgency across network actors accelerates network-level resource orchestration.*

**A sense of urgency and circumventing requirements.**

The sense of urgency generated by the pandemic prompted a fast response that went beyond what the organizations would normally consider in running their business. It was felt that only by circumventing some formal certification requirements would they manage to achieve the speed the situation required.

The critical conditions in which these network actors were operating pushed them outside normal procedures to save time. Consequently, they managed to provide the swift responses that

society demanded. "*There is a lot of process and decision making and sign-off that goes into a classic [VisDes] process that we were able to avoid … we would never manufacture and supply parts untested and unapproved in any other scenario but when we are talking about life or death situations where we could protect*" (VisDes).

Several companies sidestepped regulations related to the product or process certifications as complying with these requirements would cause too long a delay, leveraging on the grey areas of the legislation. "*Unfortunately, it takes an average of 14 – 20 months to certify a medical device … So, we followed a process where we were somehow … on the edge of legality. … if you do not have 20 months but you have two hours to not kill a person, you cannot wait 20 months*" (ValDes). Companies relied on the relaxed regulations that took place to different extents in the countries in this study. "*We have discovered, by the FDA saying it's okay for firms or people to do, not an FDA approved PPE, that we were free to go forward, on a donated basis*" (MasUser)

Circumventing certain certification requirements while trying to structure and bundle resources resulted in accelerating the products' availability to hospitals and more broadly, to society. The above arguments lead us to the following proposition:

***Proposition 1b****: A strong sense of urgency, combined with reduced regulatory oversight, encouraged circumventing tactics by network actors as they managed their resources.*

**Resource munificence and refocusing of resources**

As explained under Proposition 1a, the Covid-19 pandemic increased uncertainty of supply, demand, and labor, dramatically affecting normal operations. This led to temporary shutdowns in extreme cases and reduced operations in others, which meant that normally employed resources, such as labor, equipment and facilities, became available, resulting in resource munificence. One company stated, "…*we started to think about hiring new personnel. However,*

*we realized that some of our personnel were not 100% occupied due to the pandemic. Then we decided to do an internal pre-selection…*" (VenMan1). Resource munificence also applied to equipment, which stood idle due to lack of demand for normal products; for example, "*We had a number of external companies who were actually 3D printing them …who had spare machines that were just sitting because no-one was using them*"(VisDes).

The availability of resources caused by pandemic operational disruptions allowed companies to refocus the available resources on producing Covid-19-related products. This happened with respect to labor (e.g., *"…many people have stopped their usual work and are devoted to this project and that helps because we are working at speed"* (VenDes)), facilities and equipment (e.g., "*We got to use pretty much all of our same machinery, just repurposed it*" (MasMan2)). However, companies recognized that the refocusing of resources was only temporary, since those resources would be expected to revert to their regular business activities as demand returned. These arguments lead to the following proposition:

***Proposition 1c:*** *A temporary increase in resource munificence triggers the unlocking and the refocusing of resources previously employed in regular business activities.*

**Goal congruence and swift relationship building**

The uncertain environment and the presence of a common threat resulted in networks of actors aligning their altruistic efforts around a common goal to help their communities deal with the pandemic, suppressing competition and promoting cooperation instead. This alignment of goals among network actors meant that the process of establishing new relationships was faster than usual. The increased speed of relationship building was in part because the normal steps of supplier relationship building, such as selection and evaluation and contract negotiation, were circumvented. Suppliers, for example, would be keen to contribute to the shared and altruistic

goals of saving lives so they would supply products based on an informal trusting agreement, rather than a formal contract. This is partly because formal governance mechanisms tend to necessitate a degree of certainty (i.e., clear specifications and volumes) that was lacking in the early days of the pandemic, but also because contract negotiation is time-consuming. For example, the visor manufacturer said, "*I found a tiny little company who made elasticated ribbon and I spoke to the guy who owned the company ….. and they sent us some samples really, really quickly and they were able to adapt it…… and collaborate with us to bring out the first iteration*" (VisDes). In one case, the absence of formal contracts was due to the supplies being donated, "*The [tier 2 supplier] really was the one who responded to the call for action here, as they understood how critical the situation is, and he had the machinery and the capability and the material that we needed…. Really without his involvement and his complete donated support this would not have happened at all*" (MasMan1). New relationships quickly flourished and strengthened, as altruistic behavior emerged. Fears of opportunistic behavior were put aside, and replaced by selfless social norms, where actors contributed what they could, without expecting direct compensation. A positive-sum mentality appears to have oiled the wheels of swift relationship building.

ValDes established a new relationship with ValMould who was the snorkeling mask manufacturer, a first-tier supplier to the OEM/retailer. ValDes remembers, "*We talked to those who actually print the mask…They got in touch with us and we collected all the information related to the type of material [used in the mask]*" (ValDes). ValMould frames the exchange of information as follows: "*I received the 3D models [of the mask] directly from the OEM/retailer who we work for. We weren't authorized to release them but [ValDes] asked the OEM/retailer directly. So, for us it was easy because we had the approval from our client*" (ValMould).

Given the above evidence, we propose the following:

***Proposition 1d:*** *Goal congruence among network actors supports swift relationship building.*

**Network-level resource orchestration and value creation**

In response to the pandemic, the four emergent networks deployed resource orchestration to structure the network's resource portfolio, bundle their collective resources to build capabilities, and leverage those capabilities to deliver value to a group of network beneficiaries (i.e., organizations and individuals who directly benefited from the outputs of the networks, such as hospitals, healthcare workers, patients and vulnerable population). This is poignantly illustrated by a quote from VenDes, who orchestrated resources across two manufacturers to design, manufacturer and deliver ventilators to hospitals, "*About 20 ventilators were produced for the first clinical trial and those were manufactured by [VenDes, VenMan1 and VenMan2], standardizing the manufacturing process. Then after, they produced about 500 ventilators…to be sent to Colombian hospitals.*" These hospitals "*are using our ventilators because they don't have any more commercial ventilators, and they have many patients with Covid there, right now."* (VenDes).

Across all cases, it was evident that the products supplied by the emergent networks 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, visors, or ventilators, all the organizations expressed being praised by members of their communities who recognized the value of their efforts.

Since the products being supplied by the emerging networks were supplied for free or at cost, the network actor did not benefit economically from their efforts and did not create value for themselves. However, the beneficiates of products were grateful for the support of these

emergent networks: "*The hospitals were super appreciative that we could do this for them. We got huge pats on the back from these guys*" (MasMan1). Knowing that they were delivering value to vulnerable people in their communities caused a sense of satisfaction and pride, particularly for those delivering supplies to the front lines: "*… the most rewarding thing to do [was] to turn up at a hospital that was in dire need of PPE, and you basically knocked on their door and said 'here you go, you've got a couple of hundred face visors now that are in the back of the car*" (VisDes).

Value in the context of this research refers to the utility created by network actors on behalf of a beneficiary who uses or consumes the products. This is in line with Valerie Zeithaml's (1988: 14) definition of consumer value as "*the overall assessment of the utility of a product based on perceptions of what is received and what is given*." However, we use the term beneficiaries, rather than customers or consumers, because in our cases these actors perceived utility without necessarily paying for a product or service. We thus propose:

***Proposition 2a:*** *Network-level resource orchestration allows network actors to create value for network beneficiaries.*

**Network-level resource orchestration and goodwill**

These organizations not only managed to create value for the beneficiaries, but they did so altruistically, engaging in crisis response and donating their time and materials to the relief effort. As nicely expressed by one manufacturer: "*This is not a business. We hope we can break even if we would do this for a longer time, but ultimately we are in this to help*" (MasMan2). Their decision to act altruistically generated goodwill and positive publicity for them. For instance, ValDes received a great deal of attention in the international press, boosting the company's reputation and potential future sales; as their CEO remarked: "*We spent € 80,000,*

*which never returned. Actually, it ends up being the biggest marketing investment I've ever made*" (ValDes), and these even let to a refocusing of their business, as the CEO acknowledges: "*The … project gave us a lot of visibility, so we were recognized as "experts" in everything is related to Covid or a similar area, even if we did not have any previous experience. …. So presently we are rather focused on the health sector, in some way bactericidal disinfection or similar.*" (ValDes).

The interviews also revealed a willingness, among network actors, to share the good press with everybody in their network: in the visor case, the lead organization – VisDes, issued a press release acknowledging all of the suppliers that supported their relief effort.

The notion of goodwill we identified in our cases is consistent with Dore's (1983: 460) definition of goodwill as "*the sentiments of friendship and the sense of diffuse personal obligation which accrue between individuals engaged in recurring contractual economic exchange.*" However, instead of generating obligations at a personal level, they occur at an organizational level. We thus propose:

***Proposition 2b:*** *Network-level resource orchestration, conducted altruistically, generates goodwill for network actors.*

**Network-level resource orchestration and risk exposure**

As described in Proposition 1b, a strong sense of urgency, combined with a decrease in (or absence of) regulatory compliance, fueled the use of circumventing tactics in resource orchestration. While this resulted in an increased speed of supply to the users of PPE and medical equipment, circumventing tactics also introduced significant risks to the network actors.

In the case of Valve and Mask networks, for example, legal concerns were permeating actors in multiple tiers. Manufacturers of PPE in both networks were extremely concerned about the

reputational or financial ramifications of potential legal actions against them. The valve developer and designer stated "*The legal issues were my biggest problem. I had four lawyers working alongside me, three of whom told me "You're crazy, don't do it", because of course it was a very high risk*" (ValDes). The situation was identical in the US network. Both suppliers/manufacturers of masks and the mask user agreed to dissolve their relationship once the supply situation stabilized through the user's regular supply channels. The reason for this was that both the buyer and suppliers did not feel comfortable with continuous legal exposure in case of lawsuits from patients or medical staff if they were to contract Covid-19 or any other disease related to the use of officially non-approved face masks.

Moreover, the absence of non-compliance of manufactured PPE with federal regulations was not the only concern of our network actors. Circumventing supplier onboarding protocols, lack of proper equipment testing, shortened and often improvised NPD processes, just to speed up process flows, relationship building and meet the required demand for PPE, led to concerns over operational risks exposure. In the case of the UK network, changes to manufacturing process speed on the manufacturing equipment that has not been designed and calibrated for the increase in the required throughput led to quality issues with produced parts, and this is captured in the following quote: "*...there is a lot of complicated science as to how you set up these printers and if you set it on a really fast cycle, producing at a much faster rate, the part isn't as robust and so it was breaking and so we then had to think about introducing some quality checks*" (VisDes).

Risk exposure was sometimes shared with other network actors and beneficiaries: "*We had to tell the hospital that if they wanted to use non-certified equipment they would have 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?" If the Health Ministry gives the approval then the hospital can use it. At the end no hospitals have ever had any formal approval. Therefore those hospitals more compliant with the law did not use them. Many others have used it without declaring it*." (ValDes)

It appears that as organizations as deployed circumventing practices to accelerate product development and manufacturing, they exposed themselves to risks associated with product quality and performance, supplier quality and delivery risks, legal risks and regulatory compliance risks, which could, in turn, affect the future performance of the organizations. In general, interviewees conveyed a concern that their tactics could lead to negative implications for their organizations in the future, which fit Bogataj and Bogataj (2007: 291) conceptualization of risk as "*the potential variation of outcomes that influence the decrease of value added at any activity cell in a chain*." Thus we propose:

***Proposition 2c:*** *Speed of response can lead to increased risk exposure for network actors and beneficiaries.*

**The consequences of risk exposure**

While the exposure to the operational, reputational, and legal risks was a concern for multiple actors across all cases, most actors acknowledged the risks but tolerated them during the spike of the crisis – when human lives were on the line. Once the short-term pressure to meet the demands of buyers somewhat subsided, multiple actors indicated they would find it difficult to justify a long-term engagement in an operation where the need for the speed of response required taking circumventing processes and resulted in untested and sometimes sub-par quality products, without a legal framework that would protect them from liabilities. This is captured, for example, in the quote of one of the US PPE suppliers: "*Yes, we were able to respond and it was really like a crash. But if you gave the company more time to decide if they should do this, we probably,*

*without the regulatory thing in place wouldn't do it. I think also several other companies would have easily decided not to do it*" (MasMan1). As per resource orchestration theory, managers should constantly monitor the external environment and adjust how their resource management processes are managed to ensure value creation for customers and wealth for the owners. In this study, it was evident that the adjustment of the resource management process is not only influenced by benefits generated for the network members and changes in the external environment but also by the risk exposure in generating these benefits.

The above arguments lead to the following proposition:

***Proposition 3:*** *Risk exposure reduces network actors' willingness to continue their involvement in the orchestration process.*

Figure 1 presents the resource orchestrating model, grounded on Sirmon et al.'s (2007) original model, and shows the theoretical elaboration resulting from our propositions.

----------Insert Figure 1 Approximately Here----------

## DISCUSSION

This research investigated how actors organized around emerging supply networks and used their cumulative resources and capabilities to orchestrate a response to the Covid-19 pandemic. We built on resource orchestration theory (Sirmon et al., 2007) and followed a theory elaboration approach with abductive reasoning. The findings are captured in a set of eight propositions, which we summate in an empirical framework of network-level resource orchestration for crisis response. In doing so, we make several important theoretical and practical contributions.

*First*, we contribute to theory by extending resource orchestration to a network level. The

four networks we investigated emerged in response to a crisis but showed the same key processes outlined by Sirmon et al. (2007) as critical for orchestrating resources at an organizational level, i.e., resource structuring, resource bundling, and capability leveraging. In our cases, these processes extended across networks of organizations to respond to a high level of environmental uncertainty, particularly a severe scarcity of PPE and medical equipment. This scarcity, combined with the perceived threat of a global healthcare crisis, led to three factors, which our study shows drove network formation in this extreme uncertainty environment: a sense of urgency, goal congruence and resource imbalance. A sense of urgency that mobilized organizations to join networks of actors with complementary resources. In this process, network actors shifted their orientation from 'individual' towards a 'collective' in pursuit of a common goal or goal congruence. 'Unity under threat' is an effect documented in other social units such as the behavior of individuals to identity threats (Flade et al., 2019), organizations' response to environmental threats (Chattopadhyay et al., 2001) or nations' response to a crisis, such as Covid-19 (Zemojtel-Pietrowska et al., 2021), while this work documents it at a network level. Resource imbalance in the supply chains was the third network formation driving factor, which was caused by disruptions to supply, demand, and labor availability. Resource imbalances, found across all case studies, manifested themselves as shortages (or surpluses) of resources among the network members, who attempted to address shortages by linking with new suppliers, finding alternative materials, and essentially restructuring the networks to address the imbalances.

*Second*, our research contributes by identifying previously overlooked tactics that can be used by network actors to accelerate the resource orchestration cycle time, which involves structuring the network's collective resources, bundling them into capabilities, and deploying

them. These tactics are depicted in propositions 1b, 1c and 1d: circumventing, resource unlocking and refocusing, and swift relationship building.

The *circumventing tactic* (e.g., bypassing supplier onboarding protocols, improvisations during the NPD process, use of non-certified or tested manufacturing equipment) used in the structuring and bundling of resources resulted in accelerating the products' availability to hospitals and was particularly prevalent in all cases. In its nature, this tactic resembles Sirmon et al.'s (2007) 'entrepreneurial leveraging strategy,' which together with the identified tactics were used for rapid capability development and deployment, requiring organizations and their emerging networks to adjust swiftly to extreme environmental uncertainty (Baum and Wally, 2003).

The *unlocking and refocusing tactic* was made possible by changes in supply, demand and labor availability during the pandemic, which resulted in resource munificence in terms of labor and equipment. This allowed organizations in the network to redeploy their resources to produce Covid-related products. This is similar to the transition from dormant to active, used by military and humanitarian organizations in response to disasters (Kovács and Tatham, 2009). The main difference in our research is that most of the organizations in our networks are commercial firms, which are not prepared for a sudden engagement in a crisis response operation. Indeed, most organizations in our study recognized that the refocusing of resources was only temporary.

The *swift relationship-building tactic* involved the accelerated process of establishing new relationships to allow the emergence of a new network. The sense of urgency and goal congruence among network members triggered the formation of relationships at a faster pace than normal. Organizations sidestepped normal processes for supplier selection, evaluation and contracting, and instead relied on informal governance mechanisms based on trust. Meyerson,

Weick and Cramer (1996) use the term swift trust to refer to a unique form of collective perception that can emerge temporarily to allow actors to manage issues of vulnerability, uncertainty and risk. Tatham and Kovács (2010) show how swift trust can support the formation of hastily formed networks for humanitarian aid. In our research, we build on this notion and show how swift relationship building constitutes a key approach to resource orchestration in response to a crisis.

*Third*, our research also departs from Sirmon et al.'s (2007) original model regarding the expected outputs of resource orchestration. The original model explores the process of value creation for a firm, with price/utility and cost/utility being the two key outputs, ultimately leading to a single firm's competitive advantage and wealth creation for the owners. In our study, we examine resource orchestration in the context of health crisis response, which closely resembles what Sodhi and Tang (2021) described as 'extreme supply chain management.' A unique finding of our work is that the pursuit of competitive advantage was not the central focus for the organizations involved. This was evident in their responses, claiming that they engaged in the manufacturing of PPE because *"they wanted to help."*

Our analysis shows that network-level resource orchestration in the context of a crisis response generated a more complex set of outputs compared to the model proposed by Sirmon et al. (2007). We contribute two beneficial outputs of the orchestration process: value creation for network beneficiaries (including hospitals, and their patients, as direct beneficiaries) and goodwill generation for other network actors (designers, producers, and suppliers who benefit indirectly). As such, the beneficial outputs of the orchestration process are distributed among network members in contrast with Sirmon et al.'s (2007) model. Moreover, we also contribute a new undesirable output: risk. As networks accelerated the resource orchestration process, they

also exposed themselves to possible reputational, operational, and legal risks. The underlying mechanism that gave rise to these risks relates to the speed of network actors' response to a crisis, which is greater than the speed with which they conduct their regular business. It is necessary to clarify that increased speed was not the problem *per se*, but rather *how* network members achieved it. Bypassing supplier onboarding processes, improvised NPD processes, speeding up manufacturing equipment above the calibrated speeds, and absence of testing for regulatory compliance, are just some of the tactics network actors used to increase speed, which resulted in rapid crisis response, but not in practices that hospitals would ultimately use long-term. As a result, we observed that increased risk exposure, in combination with the absence of legal frameworks that would protect them against lawsuits, ultimately influenced their willingness to continue engaging in the crisis response.

*Fourth*, our model goes beyond Sirmon et al.'s (2007) original model and considers the impact of risk exposure in a crisis response context stemming from resource orchestration and how this reduces the willingness of actors to continue their involvement in orchestration efforts as depicted in proposition 3. Most actors in our four cases tolerated the risks (operational, reputational, and legal) during the peak of the crisis. However, when the pressure to meet the demands of buyers subsided, multiple actors indicated they would find it difficult to justify a long-term engagement in an operation where the speed of response required circumventing processes, resulting in untested and sometimes sub-par quality products without a legal framework that would protect them from liabilities.

**Implications for Practice**

This research also has significant implications for practice. First is the extreme streamlining of internal processes that took place in the response. Here, pressure from the crisis pushed organizations to redefine internal communication and decision-making processes to accelerate resource orchestration, sometimes cutting out several bureaucratic levels. Some of these redesigned flows might last even after the emergency. Indeed, streamlining internal processes could apply to less extreme conditions, such as environmental uncertainty caused by peaks in demand or competitor activity, such as introducing new products.

The second contribution to practice relates to the rapid development of practices observed. In all cases, the sense of urgency combined with shared goals among organizations in the networks facilitated rapid relationship developments. In this scenario, organizations could sidestep their normal processes for supplier selection, evaluation and contracting, but need to be confident they can rely on informal governance mechanisms based on trust.

Rapid relationship development is also related to our third practical contribution, which relates to altruistic behavior observed across all cases. The combination of uncertainty with a common threat brought organizations together around a common altruistic cause, showing how organizations are willing and able to go beyond economic incentives to help their communities under certain conditions. This illustrates an approach networks can deploy against other common threats, such as environmental and social challenges.

The fourth practical contribution concerns the unlocking and refocusing of resources, which happened in all cases due to changes in supply, demand and labor availability, resulting in resource munificence, both in terms of labor and equipment. These changes can happen due to other types of events, such as a sudden drop in demand or shortage of certain materials. Our

study suggests that organizations can redeploy their resources to produce other products in greater demand, perhaps only temporarily.

Finally, our research calls for a balanced risk management approach in crisis situations. The shortcuts taken in response to a crisis usually entail risks. Companies have learned to evaluate such risks and act to reduce them, as in the case of all the legal disclaimers for the compassionate use of given equipment/material.

**Limitations and Further Research**

This research extends resource orchestration theory to a network level. However, the scale and complexity of networks create some limitations, including restrictions on access to all network actors. We aimed to interview all network actors, and when this was not possible, we sought secondary data about additional network members from our primary sources, publicly available reports, and the media. This allowed us to form a more complete picture of the networks.

Another limitation of the research relates to our ability to reach saturation across all topics and propositions. Saturation is usually satisfied when additional constructs no longer emerge from the data analysis process. However, the theory elaboration approach starts with some pre-established constructs and relationships, making it difficult to evaluate the level of saturation achieved. While our data substantiate our propositions, further validation would help consolidate our theoretical contributions.

A final limitation is that network and organization performance and their variance was not measured in this study, and therefore it is not possible to say that managers' actions on resource orchestration (structuring, bundling, and leveraging) lead to superior results. However, we were able to show the network-level outcomes of value creation and goodwill.

Generalizability is a common limitation of case study research because the method relies on a small number of instances of a phenomenon. Our research is no different in this respect. Therefore, an avenue for further research would be to use quantitative research relying on larger datasets to confirm our findings and extend the generalizability of the propositions in other contexts, such as political or economic instability crises. In particular, it would be desirable to investigate whether the same network actor tactics to accelerate the resource orchestration cycle time (circumventing, resource unlocking and refocusing) still hold and whether additional tactics are used. Further, it would be informative to investigate if the propositions hold in less extreme scenarios thereby extending the generalizability beyond crisis scenarios.

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# TABLES

## Table 1. Resource Orchestration Process

| Stage/sub-processes | Definition | Role of Environmental Uncertainty |
|---|---|---|
| **1. Structuring resource portfolio** | The management of the organization's resource portfolio | In highly uncertain environments, organizations are unlikely to have all the necessary capabilities to respond, so acquisition and accumulation processes will become necessary. |
| Acquiring | The process of purchasing resources from strategic factor markets | During a crisis, prices fluctuate, and shortages emerge, so the ability to acquire resources becomes critical.<br>Uncertainty creates ambiguity regarding the resources needed.<br>**Slack resources** are needed to change current capabilities or develop new ones. One way of maintaining slack resources is through **real options.** |
| Accumulating | The process of developing resources internally | Uncertainty undermines the ability to respond to unexpected opportunities and threats. Organizations may create **real options** by developing their resources internally or by using **alliances** that offer opportunities to acquire new knowledge. |
| Divesting | The process of shedding organization-controlled resources | Under conditions of uncertainty, the future potential of resources to create value is difficult to evaluate.<br>Uncertainty is likely to **reduce the effectiveness of resource divestiture** decisions. |
| **2. Bundling resources** | Combining organization resources to construct or alter capabilities | In highly uncertain environments, **enriching and pioneering** processes are critical. |
| Stabilizing | The process of making minor incremental improvements to existing capabilities | Stabilizing can contribute to value creation for organizations competing under conditions of **low environmental** uncertainty. |
| Enriching | The process of extending current capabilities; although the degree of enrichment can vary, it extends beyond keeping skills up-to-date | Enrichment is frequently necessary to create new value or maintain the current value created in highly uncertain environments because of the **inability to predict changes**. |
| Pioneering | The process of creating new capabilities with which to address the organization's competitive context | The need for new capabilities is more pronounced in uncertain environments, so **pioneering becomes vital**. |
| **3. Leveraging capabilities** | The application of a organization's capabilities to create value for customers and wealth for owners | In highly uncertain environments caused by substantial and discontinuous change, an **entrepreneurial leveraging strategy** likely will be required to create value for customers. |
| Mobilizing | The process of identifying the capabilities needed to support capability configurations necessary to exploit opportunities in the market | In an uncertain environment, managers need to continuously redesign capabilities and **mobilize** them into new configurations. |
| Coordinating | The process of integrating identified capabilities into effective yet efficient capability configurations | In an uncertain environment, managers need to continuously redesign capabilities and **coordinate** them into new configurations. |
| Deploying | The process of physically using capability configurations to support a chosen leveraging strategy, which includes the resource advantage strategy, market opportunity strategy, or entrepreneurial strategy | In uncertain environments where causal ambiguity exists, tacit knowledge becomes critical to successful deployment. This is highly **personal and deeply rooted in an individual's action within a specific context**. |
| Sources: Sirmon et al., 2007; 2011 | | |

## Table 2: Case studies overview

| Cases | | Companies | | | Interviewees | |
|---|---|---|---|---|---|---|
| | Country | Name | Industry | Role in Covid-19 response | Area of responsibility | No. of interviews |
| Case 1: Masks | USA | Mask User (MasUser) | Healthcare | Healthcare provider – Buyer and user of PPE | Supply chain – operations and sourcing | 4 |
| | | Mask Manufacturer 1 (MasMan1) | Apparel – shoe manufacturer | Supplier-manufacturer of reusable and disposable masks | NPD, operations and commercial | 2 |
| | | Mask Manufacturer 2 (MasMan2) | Printing and apparel – custom printing and mascot costumes | Supplier-manufacturer of reusable and disposable masks and face shields | NPD, operations and commercial | 2 |
| Case 2: Valve | Italy | Valves User (ValUser) | Healthcare | Healthcare provider – Buyer and User of masks | Finance and Procurement | 2 |
| | | Valve Designer (ValDes) | R&D | Designer - Open source 3D Design publisher - 3D Manufacturer of valves | NPD, operations and commercial | 2 |
| | | Valve 3D Manufacturer (Val3D) | Innovation – 3D printing | Designer - 3D Manufacturer of valves and supports | Engineering and Operations | 1 |
| | | Valve Molding Manufacturer (ValMould) | Plastic molding | Supplier "Industrial" Manufacturer of valves | Business development | 1 |
| Case 3: Visor | UK | Visor User (VisUser) | Healthcare | Healthcare provider – Buyer and User of PPE | Procurement | 2 |
| | | Visor Designer Assembler (VisDes) | Automotive | Supplier – 3D printed headband and assembled visor | Commercial, Procurement and Product Design | 4 |
| | | Visor Molding Manufacturer (VisMould) | Injection molding | Supplier - Injection molded headband and assembled visor when volumes were high | *Secondary data* | - |
| | | Visor Cutting Manufacturer (VisCut) | Manufacturing | Supplier – cutter of visor elements | *Secondary data* | - |
| Case 4: Ventilator | Colombia | Ventilator Military User (VenUser2) | Military Hospital | Military hospital – user of ventilators | Procurement | 1 |
| | | Ventilator Civilian User (VentUser1) | Healthcare | Healthcare provider - user of ventilators | *Secondary data* | - |
| | | Ventilator Designer (VenDes) | Further Education and research | Product designer and developer – designed ventilator and developed commercial prototype | Commercial and Product design | 2 |
| | | Ventilator Tester (VenTest) | Healthcare device testing | Product Tester – ventilator tester | Engineering, Sales and Distribution | 2 |
| | | Ventilator Manufacturer 1 (VenMan1) | Military factory | Manufacturer – ventilator manufacturer | Operations | 1 |
| | | Ventilator Manufacturer 2 (VenMan2) | Domestic appliance manufacturer | Manufacturer – ventilator manufacturer | *Secondary data* | - |
| | | Ventilator Part Manufacturer (VenPart) | Manufacturer | Manufacturer - valves | *Secondary data* | - |
| | | | | | **Total no. of interviews** | 26 |

## Table 3: Overview of validity and reliability tactics for case research

| Validity and reliability criteria for case-based research | Applied tactics |
|---|---|
| *Internal validity* – refers to building plausible relationships between constructs (Yin, 2009). | • Development of the research framework from literature on resource management, capability development and supply chain agility<br>• Pattern matching in data<br>• Identification of commonalities in the quotes, codes, and existing theory<br>• Building explanations for within and cross-case comparisons |
| *Construct validity* – refers to correct conceptualization and operationalization of the relevant constructs (Jick, 1979, Yin, 2009) | • Grounding of the research protocol in the relevant literature<br>• Combining primary and secondary data to deepen the insight in the studied phenomena<br>• Secondary data comprised of public reports, company documents, such as product descriptions, photos of product designs, and manufacturing sites and videos of process walkthroughs.<br>• 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.<br>• Verification of case study reports by case participants. |
| *External validity* – refers to the generalization of research findings, and whether the findings can be applied to different populations or contexts (Yin, 2009) | • Use of replication logic in multiple case studies through a careful selection of the four cases based on pre-developed case selection criteria, grounded in the existing literature. |
| *Reliability* – refers to the absence of random error and enables subsequent researchers to arrive at the same insights if they would conduct the study along the same steps again (Denzin and Lincoln, 2011; Gibbet et al, 2008) | • Use of a research protocol, which consisted of a detailed data collection process and data collection instrument.<br>• Development of case study database, for all four case networks and included transcripts of verbatim transcribed interviews, secondary data such as company documents, descriptions of products, photos and videos of manufacturing sites and notes from field visits. |

## FIGURES

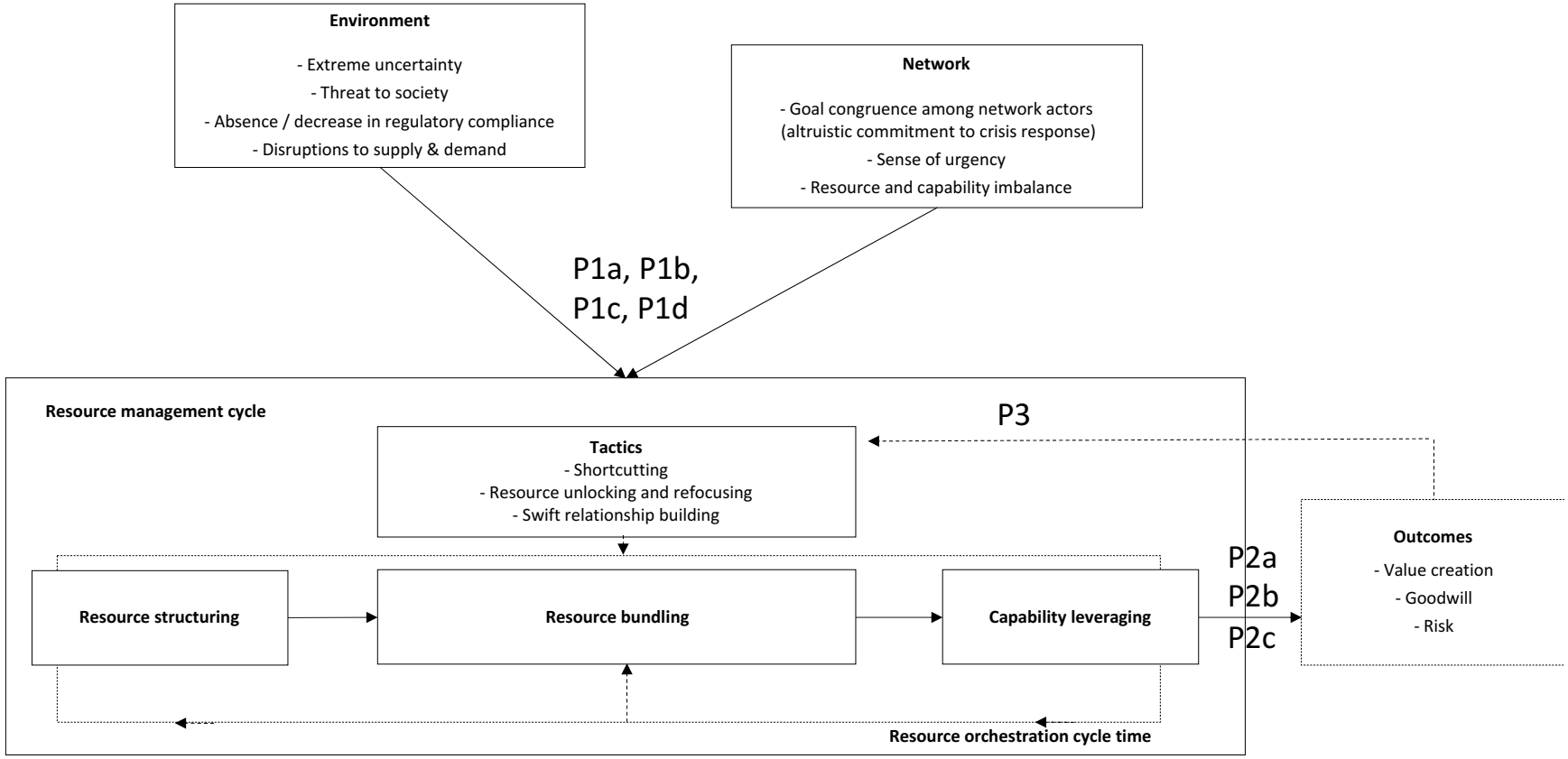


**Figure 1:** Conceptual framework developed by the study and showing the propositions

**APPENDIX 1: WITHIN-CASE CODING**

In this appendix, we provide a brief description of the four case studies, including a table in which we scrutinize the role of each of the organizations in the network, across the resource orchestration sub-processes.

## Case 1: Mask - US

| **Environment and context** | | | |
|---|---|---|---|
| **Environmental uncertainty:** *Extremely high* because of disruption to PPE supply from regular suppliers, unknown demand, non-existent alternative supply chains and time pressure<br><br>**Environmental threat:** *Extremely high* because of loss of human life and increase in the spread of the virus<br><br>**Motivation to work together:** *Very high*, because of the absence of commercial interests and presence of altruism to help and save human life | | | |
| **Key processes** | **Network Organizations** | | |
| | **Hospital - Mask User (MasUser)** | **Shoes Manufacturer - Mask Manufacturer 1 (MasMan1)** | **Printing Company - Mask Manufacturer 2 (MasMan2)** |
| **Resource structuring** | **Acquiring:** Identified local non-healthcare suppliers and worked with them on PPE specs and design with aim to purchase PPE.<br><br>**Accumulating:** Several supply chain team members' responsibilities were rapidly re-prioritized to focus on identification and selection of alternative sources of PPE supply. | **Acquiring:** MasMan1 had no existing supply chain for sourcing of materials needed to produce reusable and disposable masks. New suppliers were identified using non-traditional sources of information (friends, buyers, competitors), and onboarded without being subjected to supplier evaluation onboarding process.<br><br>**Accumulating:** MasMan1, dedicated part of the manufacturing facility for mask production, and developed equipment for masks production from parts and materials that already existed internally.<br><br>**Unlocking:** Decrease in demand for their shoes, freed up human and physical resources which became available for the development and production of masks. | **Acquiring:** MasMan2 acquired specialized materials for shields and mask through their network of existing suppliers.<br><br>**Accumulating:** MasMan2 repurposed their standard manufacturing equipment to produce shields and masks.<br><br>**Unlocking:** Due to the decrease in demand for their standard product lines, some resources (human, and physical) became available for the development and production of shields and masks. |
| **Resource bundling** | **Enriching:** Engaged in the process of prototype development and supply chain coordination with MasMan1 and MasMan2 suppliers.<br><br>**Pioneering:** Developed supplier engagement capability, based on the informal relationships and rapid onboarding without the regulatory approval. | **Stabilizing:** Workers and engineers involved in design and production learned from one another how to produce the masks and how to scale up the production volume.<br><br>**Enriching:** MasMan1 extended their capability through internal learning and knowledge acquired from interacting with MasUser during the product design and first production runs. | **Stabilizing:** Workers involved in shield and mask production learned from each other and refined the manufacturing process to meet production volumes required by the MasUser.<br><br>**Enriching:** MasMan2 extended their manufacturing capability by building on their existing knowledge and new learning on how to make face shields and masks. |

| | | | |
|---|---|---|---|
| | | **Pioneering:** Prototyping, which is normally done internally, involved multiple informal iterations between MasMan1, their buyers and suppliers, to arrive at the design that satisfied MasUser's needs, manufacturing capability and material availability from a wider supply network. | **Pioneering:** Prototyping was done in-house but with early prototype feedback from MasUser. NPD was speeded up by informal procedures and product development tools' substitution. |
| **Capability Leveraging** | **Mobilizing:** Identified key capabilities needed for the identification of new PPE suppliers.<br><br>**Coordinating:** Coordinated internal team to work with PPE end-users (e.g. doctors, nurses and patients), and NPD process with the suppliers.<br><br>**Deploying:** Deployed their coordinating capabilities to assist with NPD, and sourcing of PPE from new suppliers, as well as helping new suppliers with regulatory matters. | **Mobilizing:** MasMan1 largely utilized their already existing agile capabilities to effectively respond to the needs of MasUser.<br><br>**Coordinating:** MasMan1 had to coordinate both internal (design and manufacturing) and external capabilities (ability to swiftly deliver materials from suppliers) to be able to, design, manufacture and deliver the masks.<br><br>**Deploying:** MasMan1 deployed their internal and external capabilities but the masks were supplied under shortcutting tactics, because they were never tested to comply with FDA regulations. | **Mobilizing:** MasMan2 identified capabilities, including which can be built on, or newly developed. as well as internal and external constraints.<br><br>**Coordinating:** MasMan2 integrated their existing, altered and newly developed design and manufacturing capabilities to begin first production runs four days after the decision to become involved in face shield and mask production.<br><br>**Deploying:** MasMan2 deployed their capabilities to respond quickly to PPE shortage, However, using shortcutting tactics, the products, while approved by the buyer, were never tested to comply with FDA regulation. |
| **Outcomes** | **Intended:**<br>Securing supply of PPE.<br>Reduction of risk of disruption to healthcare provision.<br><br>**Unintended:**<br>Increase in legal risk.<br>Increase in product quality risk. | **Intended:**<br>Securing supply of PPE for MasUser helping hospitals and consequently wider community.<br>Resource re-deployment during the drop in demand for regular business.<br><br>**Unintended:**<br>Increase in legal risk,<br>Increase in goodwill and recognition<br>Learning about how agile the firm could be | **Intended:**<br>Securing supply of PPE for MasUser and helping hospitals and consequently wider community<br>Resource re-deployment during the drop in demand for regular business.<br><br>**Unintended:**<br>Increase in legal risk,<br>Increase in goodwill and recognition |

## Case 2 – Valves - Italy

| Environment and context | | | | |
|---|---|---|---|---|
| **Environmental uncertainty:** *Extremely high* because of supply disruptions of valves and masks as demand grew.<br><br>**Environmental threat:** *Extremely high* because of loss of human life.<br><br>**Motivation to work together:** *Very high*, because of the absence of commercial interests and presence of altruism to help and save human life. | | | | |
| **Key processes** | **Network Organizations** | | | |
| | **Hospital - Valve User (ValUser)** | **R&D company - Valve Designer (ValDes)** | **Plastic Moulding Manufacturer - Valve Moulding Manufacturer (ValMould)** | **3D Manufacturer - Valve 3D Manufacturer (Val3D)** |
| **Resource structuring** | **Accumulating**: Develop knowledge from the field (testing with patients) to drive medical interventions.<br>**Unlocking**: Free almost all rooms and facilities for the Covid patients (limited places kept for very severe emergencies). | **Acquiring**: Free knowledge from doctors to develop an oxygen valve to be used with existing snorkeling masks.<br>**Accumulating**: Strengthened project management capabilities and relationships with network actors.<br>Patented valve to guarantee free use.<br>**Unlocking**: Received order cancellations and devoted two people full time to managing the project (over 10,000 mails in a few weeks). | **Acquiring**: Get free use of the patent to produce the oxygen valve.<br>**Divesting**: Prepare the mold that will be used just for the emergency and then dismissed. | **Acquiring**: Acquire new knowledge on medical requirements and clinical processes.<br>**Unlocking**: The company was in a start-up phase and the Covid emergency blocked its activities. |
| **Resource bundling** | **Stabilizing**: Improve 3D printing expertise through testing.<br>**Enriching**: Support the testing of new uncertified components in clinical trials.<br>**Pioneering**: Develop collaboration with engineering/3D printing companies. | **Stabilizing**: Understand, together with hospitals and masks manufacturer, how to finetune the use for sub-intensive therapy.<br>**Enriching**: Add communication capabilities with media. Strengthen legal and risk management expertise.<br>**Pioneering**: Manage a large and distributed project relying on networks of 3D printers plus industrial molding companies. | **Stabilizing**: Finetune customer service and logistics.<br>**Enriching**: Develop advanced planning capabilities with daily reviews of the production plans. | **Stabilizing**: Finetune 3D printing capabilities with support of hospital and university.<br>**Pioneering**: Design fast response model for 3D printing thanks to direct contacts with the hospitals and social media use. |
| **Capability Leveraging** | **Mobilizing**: Identify need for championing the use of 3D printing, to develop mask in cooperation with doctors. | **Mobilizing**: Identify and engage the key partners: 3D printers and manufacturers. Engage lawyers to reduce legal risks.<br>**Coordinating**: Coordinate distributed effort to resolve issues quickly.<br>**Deploying**: Manage free access to valve specifications.<br>Support to 3D printers in production.<br>Support the users and maintenance. | **Mobilizing**: Identified and marshaled key capabilities to support delivery of new requirements.<br>**Coordinating**: Existing coordination capabilities were already agile.<br>**Deploying**: Deploy mass production expertise, covering major disruption in the regular supply chain. | **Mobilizing**: Act as a trusted catalyzer at the local level.<br>**Coordinating**: Coordinate a network of 80 3D printers.<br>**Deploying**: Organize the delivery of the 3D printed components to local hospitals. |
| **Outcomes** | **Intended:**<br>Availability of key components to face market shortages.<br>**Unintended:** | **Intended:**<br>Successful development of valve to transform a snorkeling mask into an oxygen mask. | **Intended:**<br>Successful *pro bono* redesign, production and shipments of oxygen valves.<br>**Unintended:** | **Intended:**<br>Focus local 3D printer networks to address market shortages.<br>**Unintended:** |

| | | | | |
|---|---|---|---|---|
| | High risk of using uncertified devices managed by limiting for emergency and under a patient disclaimer.<br>Successful collaboration with an R&D/Engineering firm.<br>Hospital as knowledge center for a patient-centered innovation. | Successful upscale of the project achieving a strong impact globally<br>**Unintended:**<br>Risk managed through clinical tests and legal disclaimers.<br>High visibility and commercial opportunities on R&D projects.<br>Public recognition internationally.<br>Supporting evidence for revising regulations during emergencies. | Provide for free uncertified devices under a disclaimer. | Develop new business model in clinical engineering to promote high-tech "craftsmanship".<br>Develop trustworthy network to be leveraged in future projects.<br>Risk managed by certification approach and constrained scope.<br>Disillusioned with "political games" and opportunistic behaviors |

## Case 3 – Visors - UK

| Environment and context | | | | |
|---|---|---|---|---|
| **Environmental uncertainty:** *Extremely high* because of insufficient PPE for hospitals caring for Covid-19 patients.<br><br>**Environmental threat:** *Extremely high* because of loss of human life due to insufficient protection against the virus.<br><br>**Motivation to work together:** *Very high*, because of the absence of commercial interests and presence of the goal to protect human life. | | | | |
| **Key processes** | **Network Organizations** | | | |
| | **Hospital - Visor User (VisUser)** | **Automotive Assembler - Visor Designer Assembler (VisDes)** | **Manufacturer - Visor Cutting Manufacturer (VisCut)** | **Molding Manufacturer - Visor Molding Manufacturer (VisMould)** |
| **Resource structuring** | **Acquiring:** Hospital signed a disclaimer document to say they are comfortable using the visor. | **Acquiring:** Polycarbonate was purchased for the visor but a global shortage caused assembly line stoppages. Headband 3D printing was acquired from many providers with idle machines. Smaller businesses were able to respond much quicker. Outsourced hospital delivery to a courier service.<br>**Accumulating:** Created assembly line in an unused building with quality inspection. 3D printed visor headband with idle printers.<br>**Divesting:** As volumes increased the assembly, and inbound components management, was outsourced to VisMould (already injection molding headband) enabling VisDes to be ready to resume normal automotive assembly. | **Acquiring:** Polycarbonate was purchased by VisDes for VisCut to cut<br><br>**Accumulating:** Cut various sample visors and then the final visor design. | **Acquiring:** Procured steel for injection molding tool after first conversation with VisDes before any commitment to ensure quick availability.<br><br>**Accumulating:** Developed single cavity and four cavity injection molding tools for VisDes and offered free of charge. |
| **Resource bundling** | **Pioneering:** VisDes delivered samples for review and testing to develop the design, particularly in terms of reusability. | **Enriching**: Procuring from very small companies required the establishment of a specific Covid-19 contract. Senior Project Champion appointed to advise on staffing, finance and procurement, and make executive decisions faster than usual.<br><br>**Pioneering**: The visor design was benchmarked against existing visors and the visor shape was designed to avoid the wearer putting their hands to their face.<br><br>VisDes employees delivered visors to hospitals, prioritizing deliveries. | | **Pioneering**: As VisDes moved to the four cavity injection molding machine and volumes increased to 63,000 per week VisMould established an assembly line. |
| **Capability Leveraging** | **Coordinating:** Visors were rationed across hospitals when demand exceeded supply requiring close communication with VisDes.<br><br>**Deploying**: Visors are reusable and used to manage surges in PPE demand, and for critical care and high usage areas. | **Mobilizing:** Identified that an existing tier 1 supplier (VisCut) could cut the visors. Protecting IP required involvement from copyright lawyers.<br><br>**Coordinating**: Procurement were in close communication with VisCut to ensure that they synchronized their activities with the short supply of polycarbonate. | **Coordinating:** In close communication with VisDes procurement to synchronize cutting with polycarbonate supply.<br><br>**Deploying**: Resource unlocked by drop in VisDes demand enabling responsive development and production capabilities. | **Coordinating:** In close communication with VisDes to support supply of the injection molding headband. Later, close communication required with VisCut and other suppliers to synchronize supplies to assembly line at VisMould. |

| | | | | |
|---|---|---|---|---|
| **Outcomes** | **Intended:** Visor used to manage surges in PPE demand in critical care and high usage areas.<br><br>**Unintended:** Nurses preferred disposable visors therefore the VisDes visors' use was predominantly by clinicians, e.g. surgeons and doctors. | **Intended Outcomes:** Visor components are simple and easy to clean enabling it to be reused. Resource unlocked by the drop in demand for cars was used to develop, the visor.<br><br>**Unintended Outcomes:** Multiple variants of the visor due to different polycarbonate specs, transitioning from 3D printing and different straps. This created complexity in terms of product labeling and tracing. | **Intended Outcomes:** Provided a quick visor cutting service to VisDes responding to increasing demand quickly.<br><br>**Unintended Outcomes:** Global shortage of polycarbonate meant that VisCut were required to be more flexible. | **Intended Outcomes:** Provided VisDes with molded headbands quickly. Later quadrupled their rate of production and established an assembly line in response to increases in demand.<br><br>**Unintended Outcomes:** Transfer of assembly from VisDes still required quality sign off of components by VisDes. Stockpiled visors but demand dropped through 2020 summer so production stopped. |

## Case 4 – Ventilators - Colombia

| Environment and context | | | | | |
|---|---|---|---|---|---|
| **Environmental uncertainty:** *Extremely high* because of insufficient ventilators and lengthy regulatory approval process for ventilators.<br><br>**Environmental threat:** *Extremely high* because of loss of human life due to insufficient ventilators and increase in the spread of the virus<br><br>**Motivation to work together:** *Very high*, because of the absence of commercial interests and impetus to save human life. | | | | | |
| **Key processes** | **Network Organizations** | | | | |
| | **Civil Hospital - Ventilator Civilian User (VenUser1)** | **Military Hospital - Ventilator Military User (VenUser2)** | **University - Ventilator Designer (VenDes)** | **Healthcare device testing - Ventilator Tester (VenTest)** | **Military Factory - Ventilator Military Manufacturer (VenMan1)** |
| **Resource structuring** | **Acquiring:** Under emergency government approval civilian hospitals acquired the ventilator prototype by declaring that insufficient commercial ventilators were available. | **Acquiring:** Military hospitals acquired prototype ventilator without needing emergency government approval. | **Acquiring:** Selection and evaluation of component suppliers based in Colombia including for the most critical component – the valve – from a German manufacturer.<br>**Accumulating:** 60-70 people across the Schools of Medicine, Engineering and Management worked collaboratively to develop the ventilator. | **Acquiring:** Select and evaluate reliable spare part suppliers for ventilator maintenance and repair.<br><br>**Accumulating:** Developing close relationships with the hospitals, regulatory bodies and suppliers to ensure highest standards of ventilator operation in the hospitals. | **Acquiring:** Purchased machine to analyze gasses and electrical analyzer for final inspection. Regulatory approval was not required for purchase due to the emergency Government dispensation.<br>**Accumulating:** Technology was transferred from VenDes to VenMan2 during production of the first 35 ventilators. |
| **Resource bundling** | | **Pioneering**: Worked with VenMan1 to ensure the ventilator design would meet Covid-19 patient needs. | **Enriching**: Existing capabilities in medical device prototyping were extended to develop the ventilator.<br><br>**Pioneering**: New components were developed, and through the Government emergency approval, were incorporated into the ventilator without regulatory approval. | **Stabilizing:** Refining the ventilator specification using engineering tests and the laboratory simulation tests.<br>**Enriching**: Conduct lung simulator trials and tests on pigs to verify the ventilator design.<br>**Pioneering**: For the human trials responsible for the biomedical engineering department setting up the ventilator and instructing the medical team on how to use it. | **Stabilizing:** Working as teams on ventilator manufacture and learning from each other through resolution of problems.<br>**Enriching**: Extended current capabilities in manufacturing by cooperating with the other manufacturer and learning from their capabilities producing domestic appliances.<br>**Pioneering**: Visited VenUser2 to understand needs of Covid-19 patients to further inform the ventilator design. |
| **Capability Leveraging** | **Coordinating:** Ventilators were only supplied to civilian hospitals when they declared that insufficient commercial ventilators were available, requiring close communication with VenDes. | | **Mobilizing:** Identifying volume ventilator production capabilities (at VenMan1 and one other) where capacity was available and testing capabilities from VenTest.<br>**Coordinating**: Integrating production and testing capabilities through initial laboratory lung simulator tests, | **Mobilizing:** Identifying the capabilities needed for the laboratory simulation tests, human trials, ventilator installation, clinician training and maintenance/repair.<br>**Coordinating**: Integrating the biomedical and physician capabilities in the human trials. Coordinating spare part suppliers during after sales maintenance/repair. | **Mobilizing:**. Identified internal people with relevant capabilities for ventilator manufacture (e.g. electrical engineers, technicians, and systems engineers).<br>**Coordinating**: Integrating with VenDes on the design and development, e.g. 15 prototypes were developed for the Venturi valve.<br>**Deploying**: Physically using the different capabilities in the production line. |

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| | | | tests on pigs and small-scale human trials.<br>**Deploying**: The ventilators were supplied to the civilian hospitals under a Government emergency decree. | **Deploying**: Ensuring that human trial capabilities supported successful testing and that after sales installation, training and servicing is provided responsively. | |
| **Outcomes** | **Intended:** Securing supply of ventilators for critically ill patients where insufficient commercial ventilators available.<br>**Unintended Outcomes:**<br>Increase risk to patients that the ventilator may not work properly or may cause damage since human trials are not completed. | **Intended:** Securing supply of ventilators for critically ill patients.<br>**Unintended Outcomes:**<br>Increase risk to patients that the ventilator may not work properly or may cause damage since human trials are not completed. | **Intended Outcomes:** By Christmas 2020 500 ventilators had been produced and supplied to hospitals.<br>**Unintended Outcomes:**<br>Risk of hospitals not ordering: the emergency decree requires civilian hospitals to declare that they haven't sufficient ventilators and this may discourage hospitals from ordering. | **Intended Outcomes:** Engineering tests, laboratory lung simulation tests and tests on pigs successfully completed<br>**Unintended Outcomes:**<br>Assessment of results from the small-scale human clinical trials by the regulatory authority is taking longer than expected and delaying the large-scale human trials. | **Intended Outcomes:**<br>Produced 135 ventilators that were distributed to hospitals. |