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# Harnessing the Power of Quasi–Supply Chains: Toward an Ecosystem Perspective for Transformative Supply Chain Management

Xianwei Shi[1] | William David Cordova Jimenez[2] | Yongjiang Shi[3] | Yufeng Zhang[4] | Zheng Liu[5]

[1]Antai College of Economics and Management, Shanghai Jiao Tong University, Shanghai, China | [2]Cambridge Design Partnership, Cambridge, UK | [3]Institute for Manufacturing, Department of Engineering, University of Cambridge, Cambridge, UK | [4]Department of Management, Birmingham Business School, University of Birmingham, Birmingham, UK | [5]School of Business, Operations and Strategy, Greenwich Business School, University of Greenwich, London, UK

**Correspondence:** Zheng Liu (z.liu@greenwich.ac.uk)

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## ABSTRACT

Although emerging transformative supply chain management research offers novel insights into tackling extreme conditions beyond the traditional static and engineering view of supply chain management literature, relatively less is known about the underlying mechanisms of such a supply chain transformation process. Through a qualitative study undertaken on Penlon's ESO2 Emergency Ventilator Project in the UK—a project to create a new ventilator supply chain to respond swiftly to the urgent demand that occurred due to the COVID-19 pandemic—the analysis offers a process model of transformative supply chain management by leveraging the *quasi–supply chain* that features collaborations with an ecosystem of diverse partners beyond the existing suppliers in the medical device sector. This article enriches the backbones of the emerging transformative supply chain management research and offers new insights into supply chain management for extreme conditions with an ecosystem perspective. The findings also offer managerial and policy implications for cultivating the reciprocities between supply chains and the wider ecosystem to be better prepared for future disruptions.

## 1 | Introduction

Recent episodes of turmoil—the COVID-19 pandemic, the climate and biodiversity crises, the Russo-Ukrainian war, and the Gaza-Israel conflict—have rendered unpredictable "extreme conditions" (Sodhi and Tang 2021, 7) to supply chain management. One recurring feature that underpins the resolutions to these extreme conditions lies in "collaborations beyond supply chains" (Shen and Sun 2023, 1) with "a structure of adaptive cycles" (Wieland 2021, 58), transcending what the traditional static and "engineering" view of supply chain management literature could offer (Wieland and Durach 2021).

Indeed, recent scholarly attention has been drawn to transformative supply chain management that tackles the wicked problems confronting supply chain practitioners and policymakers in the volatile world (Gómez and Lee 2023; Gualandris et al. 2024). Such a novel approach accounts for contextual factors beyond the supply chains per se (Wieland 2021) and examines key antecedents that support transformative supply chain resilience

(Mirzabeiki and Aitken 2023). This stream of research considers how supply chain management should embrace "adaptation and transformation" (Wieland and Durach 2021, 315), instead of stability, in order to effectively combat extreme conditions (Sodhi and Tang 2021).

As an emerging topic of research, the transformative supply chain management literature has offered important insights into the key environmental factors and driving forces for the adaptative cycles (Gualandris et al. 2024; Wieland 2021; Wieland and Durach 2021). However, relatively less is known about the underlying mechanisms of how such a transformation unfolds when engaged with external resources in the turbulent environment. In particular, substantial debates still exist pertaining to the boundary and scope of the external resources beyond the supply chains (Mollenkopf et al. 2024) that are involved in such a transformation, as well as debates regarding just how these resources can be reconfigured to enable supply chains that are "dynamically adaptable and capable for rapid structural changes" (Dolgui, Ivanov, and Sokolov 2020, 4139). These debates may therefore benefit from bringing in perspectives that take into account factors that are "outside of the firm's immediate operations and supply chain flow in the overall ecosystem" (Cohen and Kouvelis 2021, 634).

The ecosystem perspective, defined as a community of multiple coevolving and interdependent players that span various industries (Bendoly and Tang 2021; Iansiti and Levien 2004; Moore 1993; Rong et al. 2015), offers a promising avenue to address this research lacuna. To this end, and by employing an ecosystem perspective, this article is built upon an explorative qualitative study of Penlon's ESO2 Emergency Ventilator Project ("Penlon Project" for short) that was led by the Ventilator Challenge UK (VCUK) Consortium in order to produce ventilators locally to support the UK's National Health Service (NHS) during the COVID-19 pandemic. This newly formed supply chain sought to meet novel, emergent demands with an entirely new set of suppliers that were outside of the medical device sector.

Utilizing Penlon Project case analysis, this research theorizes the process that features collaborations with an ecosystem of diverse partners (Shi, Liang, and Ansari 2024) as an ecosystem perspective to transformative supply chain management. Central to this ecosystem are untapped resources in a *quasi–supply chain*, which can be defined as a range of product-specific resources (e.g., distinctive technologies and patents), general-purpose resources (e.g., skills and competence and components spanning various industry sectors), and relations and trust (e.g., interorganizational relationships), which can be coordinated and transformed toward a new supply chain in response to extreme conditions. This research offers a process model of how such a supply chain transformation unfolds from an ecosystem perspective. Specifically, it identifies the transformation and reembedding mechanisms that are present between quasi–supply chains and newly established supply chains.

This research offers several contributions to literature. First, it contributes to the emerging stream of research on transformative supply chain management (Gualandris et al. 2024; Mollenkopf et al. 2024; Wieland 2021) by theorizing an ecosystem perspective to the underlying processes of transformative supply chain management. By invoking the quasi–supply chain as the key factor upon which an ecosystem is built, it points to specific resources that firms may tap into when their supply chains confront extreme conditions. Second, with the concept of quasi–supply chain, this research demonstrates how the ecosystem perspective may offer fresh insights into supply chain management for extreme conditions (Bendoly and Tang 2021; Ketchen, Crook, and Craighead 2014; Sodhi and Tang 2021; Wu and Jia 2018). Such a novel concept contextualizes and integrates a bundle of scattered concepts in supply chain resilience literature, such as the "stand-by capabilities" (Bendoly and Tang 2021), "reconfigurability" (Dolgui, Ivanov, and Sokolov 2020), and "preparedness of supply chains" to cope with extreme conditions (Kovács and Falagara 2021; Sodhi and Tang 2021). The findings also serve to inform practitioners and policymakers as to how they may better cultivate the reciprocities between supply chains and the wider ecosystem so that they may be better prepared for future disruptions.

The rest of the article is organized as follows: Section 2 discusses the key literature that exists regarding transformative supply chain management and the ecosystem perspective. Section 3 describes the qualitative methods, and Section 4 presents an overview of the case study, analyzes the findings, and presents a theoretical framework from the analysis. Finally, Section 5 concludes the article with theoretical, practical, and societal implications and suggests potential avenues for future research.

## 2 | Theoretical Background

### 2.1 | Supply Chain Management for "Normal" Conditions

The extant literature primarily considers two main scenarios that underpin supply chain management for "normal" conditions. The first scenario considers the process of supply chain management that unfolds in an intentional manner throughout daily operations as managers pursue greater operational efficiency and effectiveness (Sodhi and Tang 2021; Wadhwa, Saxena, and Chan 2008; Payne and Peters 2004). It may also unfold in an emergent manner to build resilience against risks (Shu, Lv, and Na 2021; Speier et al. 2011) when the original sets of suppliers are unavailable or address sustainability issues when existing suppliers are under more stringent scrutiny from the regulators and the wider public (Matos et al. 2024). Specifically, the first scenario in supply chain management considers the efficiency, effectiveness and sustainability of day-to-day operations (Meixell and Gargeya 2005; Payne and Peters 2004; Piramuthu 2005; Wadhwa, Saxena, and Chan 2008). Such a scenario mainly places focus upon optimizing existing, well-defined products with a relatively stable set of suppliers and offers useful insights on how to optimize the design, operations, and technologies of supply chains so as to enhance their performance and improve their effectiveness and sustainability (Reich et al. 2021). Some studies seek to explore novel methods and metrics to evaluate supply chain configurations (Piramuthu 2005), while others employ analytical approaches that examine various measures of optimizing supply chain designs, such as push–pull alternatives (Yang, Cai, and Chen 2018).

While the first scenario focuses primarily on the optimization of the existing supply chain, the second explores how to design a resilient supply chain that is sufficiently robust to normal disruptions, such as regulation disruptions (Phadnis and Joglekar 2021), natural disasters (Sodhi and Tang 2014), and food shortages (Bottani et al. 2019), which often occur alongside local impacts, the risk of which can sometimes be predicted. These normal conditions may affect the existing suppliers in such a way that predefined, well-established products cannot be manufactured, thus emphasizing the importance of both connectivity (Brandon-Jones et al. 2014) and the invocation of new sets of suppliers (but still within their existing scopes of production) that may continue the production of well-established products when the original suppliers are not available (Abushaikha, Wu, and Khoury 2021; Wu and Jia 2018).

## 2.2 | Transformative Supply Chain Management to Tackle "Extreme" Conditions

While prior research has offered useful insights into supply chain management under *normal* conditions, a critical assumption considers that these studies lean toward a static, "engineering" view of supply chain management (Wieland and Durach 2021, 315). For example, although prior research sheds light upon tackling supply chain disruptions that contain products that are well defined and suppliers that are known ex ante, much less is known about supply chain management under extreme conditions (Sodhi and Tang 2021), when product specifications continue to evolve, and suppliers are unavailable from the original sector. Such extreme conditions indicate the need to manage a supply chain with new sets of suppliers who are outside the sector. While a focal organization is often in place to lead the endeavors in extant supply chain management literature, these extreme conditions may require multiple organizations simultaneously driving progress across a series of evolving events (Sodhi and Tang 2021).

Understanding the underlying mechanisms of supply chain management in such extreme conditions is particularly important in a volatile world in which disruptions resulting in global impacts often dramatically decrease the ability of an organization to meet provisional and unpredictable demands, such as the production of medical devices amid the COVID-19 pandemic (Shen and Sun 2023). These extreme conditions may also be caused by geopolitical conflicts or wars that are not only hard to predict but also involve major world powers; these conditions will also lead to widespread humanitarian disasters that affect trade, economies, and global stability (Abushaikha, Wu, and Khoury 2021). It is also highly relevant in tackling other extreme conditions that are difficult to prepare for, such as the climate crisis that has resulted in more frequent and more intense extreme weather events, or rising sea levels, or changes in agricultural yields (Azadegan and Dooley 2021).

Beyond the traditional, static "engineering" view of supply chain management, the emerging stream of research on transformative supply chain management responds to tackling grand challenges and wicked problems with a social-ecological view (Gualandris et al. 2024; Matos et al. 2024; Wieland 2021; Wieland and Durach 2021). Indeed, the consequences of extreme conditions may prompt organizations to create and deliver offerings that are outside of their traditional boundaries of production (Shaheen and Azadegan 2020). The increase in such extreme conditions also presents organizations with an urgency to transform their supply chains to be "dynamically adaptable and capable for rapid structural changes" (Dolgui, Ivanov, and Sokolov 2020: 4139). Such transformation requires metastructures beyond the boundaries of predefined, well-established supply chain members (Dolgui, Ivanov, and Sokolov 2020). Therefore, it presents a challenge to the long-standing static and reductionist view in supply chain management (Wieland 2021).

These extreme conditions may urge organizations to seek "collaborations beyond supply chains" (Shen and Sun 2023, 1) and provoke risks that are "outside of the firm's immediate operations and supply chain flow" and "may have to … account for the changes to the overall ecosystem" (Cohen and Kouvelis 2021, 634), tapping into resources that "exist not at the level of the firm, but at the level of the ecosystem" (Jacobides, Cennamo, and Gawer 2018, 2270), and are therefore critical for managing extreme conditions (Bendoly and Tang 2021). The scope and boundary of such resources, however, are relatively unknown. In addition, the underlying mechanisms of how such a supply chain transformation unfolds when engaging with these external resources remains largely silent in the extant literature.

A business ecosystem, defined as a community of multiple coevolving and interdependent players that span various industries (Adner 2017; Rong et al. 2015), offers a promising perspective that serves to address this research gap. Such an ecosystem perspective is used to represent both an "expanded collection of harnessed entities and tactics" (Bendoly and Tang 2021, 2343) and to address challenges that exist within highly uncertain and complex environments (Rong et al. 2015). The ecosystem perspective is valuable with reference to this case study because it offers a unique opportunity to examine supply chain management for extreme conditions, which is simultaneously and collectively driven by multiple organizations beyond the boundaries of existing supply chains (Viswanadham and Samvedi 2013) and spans a wide range of industries (Rong et al. 2015). In addition, it is a unique tool that will clarify the resources required for transformative supply chain management and the key mechanisms that drive such a transformation. Hence, this article answers the following research question: *From an ecosystem perspective, how do organizations transform a supply chain in response to extreme conditions?*

## 3 | Methods

In order to answer the above research question, this research has adopted a qualitative approach, which is appropriate because the phenomenon at hand is not well understood within extant literature (Ketokivi and Choi 2014; Wieland, Tate, and Yan 2024). Specifically, this research has attempted to go beyond a traditional template (Wieland, Tate, and Yan 2024) and combine the Gioia approach (Gioia, Corley, and Hamilton 2013) with process theorizing (Langley 1999). This is particularly suitable as this research focuses on "temporally evolving processes" to make sense of the underlying mechanisms of the VCUK supply chain transformation rather than explaining variance (Gehman et al. 2018, 289).

Specifically, this research has employed the Gioia approach to categorize data and develop new concepts (Gioia, Corley, and Hamilton 2013), as it can demonstrate a clear chain of evidence and has been widely adopted throughout supply chain management research (Quarshie and Leuschner 2020; Wu and Jia 2018). In addition, to reveal the temporal dynamics and evolving features of transformative supply chain management, this research has incorporated process theorizing (Langley 1999; Langley et al. 2013; Pettigrew 1992; Van de Ven 1992) by applying "temporal bracketing" in conjunction with "visual mapping" strategies (Langley 1999; Langley et al. 2013). While Gioia's approach (Gioia, Corley, and Hamilton 2013) can improve the rigor of construct identification, the process approach has advanced the understanding of how and why events transpired (Langley et al. 2013; Van de Ven 1992), thereby revealing the temporality and interconnectedness of the identified concepts for the final process model to emerge. Consistent with process-oriented qualitative studies in the field of supply chain management (e.g., Quarshie and Leuschner 2020), the epistemological position of this research has followed social constructivism to make sense of the "socially constructed" organizations (Gioia, Corley, and Hamilton 2013, 16).

### 3.1 | Case Selection

To this end, a single case was selected for in-depth analysis: the Penlon Project, which was organized by the VCUK Consortium. It was selected for the following reasons: (1) The project was conducted in response to the COVID-19 pandemic, demonstrating the scenario where supply chain transformation was required in order to cope with complex and continually evolving demands. (2) The case presented a joint effort from organizations across the medical, technological, aircraft, automotive, and service sectors that, combined, formed a new supply chain. Thus, it provided the research setting needed to investigate supply chain management in the wider ecosystem context. (3) There was good access to data, and researchers engaged with various organizations to understand the details of the supply chain coordination from different angles and at different stages of the project. (4) There was sufficient archival data to be drawn upon, including project reports and new releases, to triangulate the data.

### 3.2 | Data Collection

The primary data were collected during 2020 and 2021 via semistructured interviews, utilizing 17 organizations and 25 individuals (indexed as I1, I2, ..., I25 in Table 1) within the Penlon Project. The interviewees held the positions of supply chain managers or project managers, and they were directly involved in the project and aware of the interactions between various organizations. Following the sample questions in Table 2, each interview lasted for roughly 60 min, generating a transcript of 5500 words on average. The interviews continued until various aspects of the project had been covered, indicating a sufficient theoretical saturation point (Glaser and Strauss 1999). Archival data were also collected including the Penlon Project reports, participants' websites, third-party interviews, and news releases (Table 3).

### 3.3 | Data Analysis

Data analysis began with Langley's (1999) process approach to reveal the temporal dynamics of the VCUK project, followed with the three-level grounded coding (Gioia, Corley, and Hamilton 2013). The procedure used to analyze the data is illustrated in Figure 1. The coding process is mainly inductive yet still guided by and constantly iterated with existing literature, following the example set by Quarshie and Leuschner (2020).

As Figure 1 shows, the data analysis began with a "visual mapping" strategy (Langley 1999) that outlined the key events marking the development of the Penlon Project onto the timeline, clearly showing "who did what and when" (Chen, Dooley, and Rungtusanatham 2016; Langley 1999). This was achieved through the examination of the archival data alongside the primary data.

Then, a "temporal bracketing" strategy (Langley 1999) was followed to examine the evolving connections among the events, highlight the clear temporal breakpoints (Langley 1999), and accordingly divide the Penlon Project into four successive time periods/phases (Nair et al. 2015; Sting, Stevens, and Tarakci 2019). Phase 1 was from March 15, 2020, to March 20, 2020, showing early stages of the project and consortium formation. The first triggering event was the UK government call. Phase 2 was from March 21, 2020, to April 13, 2020, concerning product development and supply chain formation. The delivery of the first batch projects marked the full establishment of the Penlon Ventilator supply chain. Phase 3 was the production acceleration to fulfill NHS demand. The project ending date July 5, 2020, indicated the disintegration of the Penlon Ventilator supply chain. Phase 4 was the continuation of learning and new collaborations among the project members, spanning from July 6, 2020, to present.

Afterwards, the research team followed the three steps of coding defined by Gioia, Corley, and Hamilton (2013). In the first step, each of the five authors independently read the transcripts and conducted open coding in order to identify the key contexts and activities that occurred during the Penlon Project. The open codes were then collectively compared, discussed, and confirmed, which resulted in 21 primary codes (first-order codes), which are shown in Tables 4 and 5. For instance, the code "preexisting relationship" reflected "We work with a number of the companies that are in the consortium" (I12) and "We got involved because of my connection with HVMC" (I20), as the interviewees emphasized the importance of previous connections when the project was being formed. Similarly, the code "common vision" was derived from the quotes highlighting "People just work together for a common goal" (I4), "All had a common goal" (I11), and "It was the goal, everybody wanted to do something" (I19).

In the second step, building further upon the primary codes, all authors worked together to generate axial codes by comparing

**TABLE 1** | Sample of organizations and interviewees.

| Organization | Original industry | Role in VCUK | Interviewee position | Index | Time |
|---|---|---|---|---|---|
| Accenture | Technology | Supporter | Managing director | I1 | Jul 2020 |
| Airbus | Aircraft OEM | Subassembly | Project manager | I2 | Jan 2021 |
| | | | Supply chain manager | I3 | Feb 2021 |
| Ford | Automotive manufacturer | Subassembly | General manager | I4 | Feb 2021 |
| HVMC | Research center | Leader/coordinator | CEO | I5 | Jun 2020 |
| | | | Coordinator | I6 | Jan 2021 |
| McLaren | Formula One racing automotive manufacturer | Parallel supply chain (parts) | Director on innovation | I7 | Jul 2020 |
| | | | Project manager | I8 | Feb 2021 |
| Meggit | Tier-1 aerospace supplier | Supplier | Global VP program management | I9 | Jul 2020 |
| | | | Supply chain manager | I10 | Feb 2021 |
| Microsoft | Software technology | Digital tools | Head of cloud solutions | I11 | Jul 2020 |
| Penlon | Medical device manufacturer | Design/IP provider<br>Final testing | Head of IT | I12 | Jul 2020 |
| | | | Head of products and marketing | I13 | Feb 2021 |
| PTC | Computer software and services | Digital transformation supports | VP business development | I14 | Jul 2020 |
| Quick Release | Product data management solutions | Product data management | Director | I15 | Jul 2020 |
| Rolls-Royce | Aircraft engine manufacturer | Supporter | Project manager | I16 | Jun 2020 |
| | | | Digital director | I17 | Jul 2020 |
| | | | Head of global supply | I18 | Feb 2021 |
| Siemens Digital Industries | Industrial engineering/digital technology | Digital expertise | Head of factory | I19 | Jul 2020 |
| Siemens | Industrial engineering/medical technology | Medical expertise | Managing director | I20 | Jul 2020 |
| STI | Contract electronic manufacturer | Final assembly | Executive director | I21 | Jul 2020 |
| Thales Training and Simulation | Training solutions | Training<br>Parts design | Head of systems engineering | I22 | Jun 2020 |
| | | | Project manager | I23 | Jul 2020 |
| Ultra Electronics | Electronics manufacturer | Assembly support, testing support | Head of capabilities | I24 | Jul 2020 |
| Williams Racing F1 Team | Formula One engineering/technology service | Engineering resource<br>Final testing | Aerodynamicist/final testing engineer | I25 | Jul 2020 |

**TABLE 2** | Interview questions.

| |
|---|
| Transformative supply chain (Penlon's ESO2 Emergency Ventilator Supply Chain) related:<br>• *What was your organizational role in the Penlon supply chain?*<br>• *What made this supply chain different from your previous supply chain? Why was that?*<br>• *What were the main challenges of this supply chain?*<br>• *How did you manage to solve the problems quickly?*<br>• *How did you share knowledge and work together with other partners in the supply chain?*<br>• *How did you integrate knowledge from external sources?*<br>• *What is your view about the performance of the Penlon Ventilator supply chain?* |
| Ecosystem-related questions:<br>• *Why did you join the VCUK Consortium?*<br>• *What was your specific role and contribution?*<br>• *Was the role changed during the project?*<br>• *What happened first when you joined the consortium? What happened next?*<br>• *Have you worked with others from the VCUK Consortium before?* |
| Supply chain management–related questions:<br>• *How did the new project design and development take place?*<br>• *Was it different from your previous product development process? Why was that?*<br>• *What did you do to form this new ventilator supply chain?*<br>• *Was it different from your previous product development process? Why was that?*<br>• *What were the challenges in the formation of the Penlon Ventilator supply chain?*<br>• *How did you cope with the challenges?* |
| Postproject and learning-related questions:<br>• *What have you learned most from the VCUK Project?*<br>• *Are there any changes to your organization and supply chain because of the VCUK Project?*<br>• *Do you still work with other VCUK partners or their suppliers? Why or why not?*<br>• *What will you do in the future if there is another urgent requirement or government call for a new product and supply chain?*<br>• *What strategy can we use for establishing similar consortiums and be in a better position in the future?* |

similarities and differences. Through multiple iterations of discussion and categorization, six axial codes (second-order codes) were confirmed (see Tables 1 and 2). For example, the primary codes "existing product subsystems," "unique product approval experience," "high-quality standards," and "exceptional technical skill" all represent skills and knowledge that contribute directly to the ventilator product. Thus, they were grouped together and labeled as "product-specific resources." Tables 4 and 5 demonstrated more additional representative quotes that linked codes to data. These axial codes bridged the primary codes and the final themes, leading to theoretical accounts in the next step (Gioia, Corley, and Hamilton 2013).

The third step was the theoretical coding, during which the insights that had been yielded from the first two stages of the data analysis were discussed by all authors, taking into account the links between the research questions, data, and existing literature (Gioia, Corley, and Hamilton 2013; Quarshie and Leuschner 2020). With iterative discussion and confirmation among the research team, eventually, two new theoretical themes were identified and extracted from the axial codes: quasi–supply chain and re-embedding mechanisms. Accordingly, a data structure (Figure 2) was constructed to demonstrate the connections between primary data, axial codes, and theoretical themes, thus showing the building blocks of the theoretical model.

The above three steps of coding were iterative, while the research team actively compared the process phases identified earlier with the themes categorized via Gioia's approach (Gioia, Corley, and Hamilton 2013) to ensure consistency. Specifically, Phase 1 was the formation of "quasi–supply chain." Phase 2 was in parallel with the functions of "transforming mechanisms." Phase 3 was the full operations of the "supply chain." Phase 4 showed "re-embedding mechanisms" returning the supply chain capabilities back to the quasi–supply chain.

Finally, the research team brought together the axial codes and theoretical themes and elaborated upon the connections between them. Informed by process theory (Langley 1999; Langley et al. 2013; Pettigrew 1992; Van de Ven 1992), such connections are made based on (1) temporal dynamics and "the passage of time" (Langley 1999, 700), indicating the time sequence and activity progressions (Pettigrew 1992; Van de Ven 1992), and (2) causes and effects, showing the driving forces, nonlinear relationships, and feedback loops to make sense of "mutual shaping" and "mutual influences" (Langley 1999, 703; Nair et al. 2015).

For example, from temporal dynamic perspective, the operations of "supply chain" happened after the completion of "transforming mechanisms"; whereas "re-embedding mechanisms" temporally functioned after a "supply chain" disintegration. From causes and effects' perspective, "urgent demand" from the UK government and NHS triggered and drove the actions of "transforming mechanisms"; "product-specific resources," "general-purpose resources," and "relations and trust" constantly interacted and reinforced each other in a nonlinear way; the "re-embedding mechanisms" further enriched the "quasi–supply chain" with feedback effects. Accordingly, a theoretical model was generated, which was refined multiple times until all theoretical concepts were well integrated to answer the research question.

Following Abushaikha, Wu, and Khoury (2021), several measures were taken to ensure the robustness and trustworthiness of the results. First, to improve internal validity, when examining event timelines, the Penlon Project–related events were carefully checked across all transcripts and archival data to ensure accuracy (Chen, Dooley, and Rungtusanatham 2016). Further, to ensure confirmability, during the grounded coding, each author conducted coding independently, followed by several rounds of discussion among all authors to reach

**TABLE 3** | Archival data sources.

| Data Types | Collection details and dates | Amount |
|---|---|---|
| VCUK project reports | VCUK reports (Mar–Aug 2020) (https://www.ventilatorchallengeuk.com/) | 5 reports, 12 pages |
| Government reports | UK Government website (Mar–Jul 2020; Apr 2021) (https://www.gov.uk/government/latest?topical_events%5B%5D=coronavirus-uk-government-ventilator-challenge; https://www.gov.uk/government/news/information-relating-to-the-ventilator-challenge-and-the-statutory-residence-test) | 7 pages |
| | National Audit Office report (Sep 2020) (https://www.nao.org.uk/wp-content/uploads/2020/09/Investigation-into-how-the-Government-increased-the-number-of-ventilators.pdf) | 61 pages |
| | House of Commons report (Nov 2020) (https://committees.parliament.uk/publications/3639/documents/35370/default/) | 21 pages |
| | House of Commons meeting transcript (Oct 2020) (https://committees.parliament.uk/oralevidence/1033/default/) | 42 pages |
| Videos | Videos and third-party interview to the VCUK Consortium organizations (e.g., HMVC, Microsoft, McLaren, Ford) (2020) | 5 videos, 50 min |
| News release | BBC website (Mar 2020; Apr 2020), (https://www.bbc.co.uk/news/business-51914490; https://www.bbc.co.uk/news/business-52309294) | 2 pages |
| | Guardian website (May 2020; Sep 2020) (https://www.theguardian.com/business/2020/may/04/the-inside-story-of-the-uks-nhs-coronavirus-ventilator-challenge; https://www.theguardian.com/world/2020/sep/30/uk-spent-569m-on-20900-ventilators-for-covid-care-but-most-remain-unused) | 3 pages |
| Company reports | Airbus project summary | 2 pages |
| | Ford website (Apr–May 2020) (https://www.ford.co.uk/experience-ford/ford-blog) | 2 pages |
| | McLaren website (Aug 2020) (https://www.mclaren.com/racing/inside-the-mtc/case-study-ventilator-challenge-uk/) | 1 page |
| | Microsoft website (Jul 2020) (https://www.microsoft.com/en-gb/about/ventilator-challenge/) | 5 pages |
| | Penlon website (Mar 2020–Oct 2021) (https://www.penlon.com/Blog) | 20 pages |
| | Siemens website (Apr 2020) (https://news.siemens.co.uk/news/siemens-steps-up-to-support-the-uks-ventilator-challenge) | 1 page |
| | STI website (https://www.sti-limited.com/imi-introduces-cpap-an-alternative-ventilator-solution-for-covid-19-patients/) | 1 page |

consensus. Finally, the final process model was sent to key interviewees in VCUK for confirmation to ensure external reliability.

## 4 | Case Analysis

### 4.1 | Case Overview and Mapping

On March 15, 2020, the UK government issued an urgent request to manufacturers to produce 20,000 ventilators to treat hospitalized patients that were infected with SARS-CoV-2, a newly emerging virus. The High Value Manufacturing Catapult (HVMC), a group of manufacturing research centers located in the West Midlands, UK, established the VCUK Consortium on March 18, 2020. The HVMC brought on board Airbus, Ford, Siemens, and Penlon, who had 75 years of medical device design experience. Penlon proposed the ESO2 Emergency Ventilator on March 21, 2020, that could be manufactured using available materials. On April 5, 2020, the prototype gained medical approval with help from Siemens Healthineers.

As Penlon were able to produce only 12 devices a week, new production sites and supply chains were urgently needed to meet the requirement of rapidly manufacturing 2500 ventilators per week. McLaren set up a parallel production line to fill the gaps from global suppliers. Siemens Digital Industries used digital design to simulate production, and three subassembly lines were formed in mid-April 2020. Airbus focused on the absorber and flow meter, and Ford transformed one plant into a subassembly site for the AVS vent box and a remote display screen.

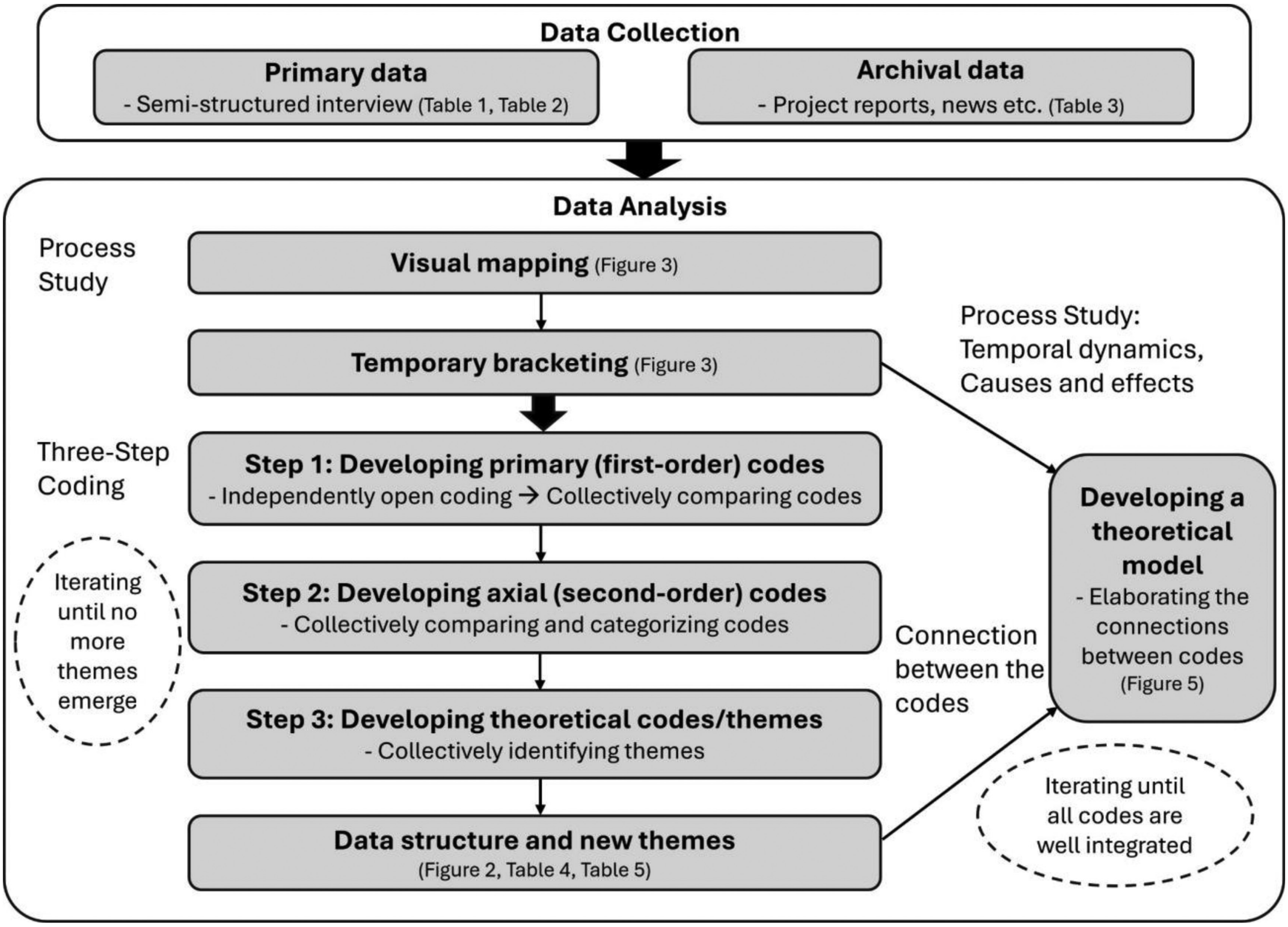


**FIGURE 1** | Data analysis process.

McLaren developed a scalable, user-friendly, and lightweight trolley. The subassemblies were sent to STI, a UK-based contract electronic manufacturer for the final assembly, and seven UK-based Formula One teams worked side by side with Penlon for the final testing. The first batch of the ventilators were manufactured on April 13, 2020, held at DHL storage units, and distributed throughout the NHS by the Defense Equipment & Support (DE&S).

Due to uncertain demand, the consortium continuously scaled-up production, with new partners joining; the number of organizations that were on board rose from nine organizations in March 2020, to 88 organizations by July 2020 (33 were directly involved in the Penlon Project). Microsoft, PTC, and Thales Training and Simulation provided assistance for the virtual training of 3500 new workers across multiple sites. The acceleration was exponential, reducing the lead time to 9 days per 100 products in May 2020 and only 2.5 days in late June 2020, 150 times faster than in early April 2020. With a total of 11,683 Penlon ventilators delivered throughout the NHS, the project ended on July 5, 2020. Penlon received the internationally recognized CE mark of approval certificate in late June 2020, and the UK Conformity Assessed (UKCA) mark in October 2021, meaning the Penlon Ventilator could then be used for a wide range of treatments. Figure 3 shows the mapping of the project and highlights the key events.

### 4.2 | Confirmation of Existing Themes

The case has confirmed two existing themes: supply chain and transformation mechanisms. Specifically, the supply chain refers to the Penlon ESO2 Ventilator supply chain that was newly established during the project. The supply chain structure is shown in Figure 4.

This supply chain demonstrated a high level of efficiency (Payne and Peters 2004; Sodhi and Tang 2021; Wadhwa, Saxena, and Chan 2008), resilience (Bendoly and Tang 2021) and orchestration capability, as companies adapted and repurposed their own production. For example, Penlon changed their drawing specifically to make it easier for new and inexperienced suppliers to work upon, whereas Airbus and Ford also adjusted their production lines. Digital technologies, including Microsoft Teams, SharePoint, HoloLens, and PTC's Vuforia Expert Capture also significantly aided communications between the supply chain partners.

Another existing theme that is notable from the results of the Penlon Project are the transformation mechanisms, which are concerned with product development and supply chain integration. Specifically, product development relied upon both the effective coordination of internal organizational resources and collaborative relationships with suppliers (Skilton

**TABLE 4** | Codes and representative quotes of the quasi–supply chain.

| Axial (second-order) code/first-order code | Additional representative quotes |
|---|---|
| Product-specific resources | |
| Existing product subsystems | I12: "As Penlon, we are a medical device manufacturer with a 75-year history in the industry. Basically, that's based on anesthesia systems with put in ventilators. So, we have products that were easily adaptable to be used. So, yeah, we actually made contacts with the medical authority within the UK, the MHRA, for all medical devices." |
| Unique product approval experience | I20: "The Ventilator Challenge UK Consortium wouldn't have had medical device manufacturing knowledge … that would have been a gap in the consortium other than Penlon themselves." |
| | I25: "Penlon being the biggest one, because the top-rated ventilator in the UK is made by Penlon." |
| High-quality standards | I22: "What was interesting about the aerospace industry is that we're used to a really high level of regulation, like medical care, and I think, as an as aerospace engineers, we looked at it we were like the likelihood of getting something new certified in this timeframe is slim to none." |
| Exceptional technical skill | I25: "The most important thing that we can contribute with is first of all, highly trained personnel in technology levels. And second, and particularly, of course a Formula One is all about rapid prototyping capacity. Anything you have to make, regardless of the material, regardless of the technical requirements, and even regardless of the tolerance quality, the manufacturing quality, this is something that Formula One is great at." |
| General-purpose resources | |
| Design capacity | I22: "And we used our skill in developing flight electronics to actually develop PCBAs for some of the more complex test boxes that needed to be used for the ventilator." |
| Production capacity | I12: "The one common denominator is that we all produce a product, whether it's wings for an airplane or cars for consumer, we all produce, so fundamentally, the ideas or the way the processes are similar." |
| Diverse skills | I20: "Siemens got involved along the lines, then it wasn't going to be manufacturing PCBs, but it was going to be expertise on digital design. So, designing the production lines, using the Siemens PLM software" |
| | I20: "HVMC came to us, saying they could make use of our skill, so they added us to the list. The consortium together from the knowledge and expertise needed and companies who had capability. Despite the fact that I felt we could bring digital manufacturing expertise and so on to this. In those early stages, I genuinely didn't know what we were going to get involved in. I just knew that we had resources and skills that might well feature as part of the answer." |
| | I11: "What Microsoft's role in that has been to give them the technology to allow them to collaborate. One of the senior leaders that was involved in the consortium. He reached out to us, specifically to say, what can we do to help them because they all came together. And they were all talking but they were all trying to share information and really badly as it came about. So he looked to us to give them a solution that would help them collaborate far easier. And that's where the journey really started." |
| Managerial experience | I5: "All of us are experienced engineers, and all of us have run complicated complex businesses and have delivered complex programs, whether they be aircraft wings, motorsport programs, or cars or diesel engines. We've all got a lot of experience in complex programs. So we all intuitively knew what needed to be done, and all had good processes in our companies to do that." |

(Continues)

**TABLE 4** | (Continued)

| Axial (second-order) code/first-order code | Additional representative quotes |
|---|---|
| Relations and trust | |
| Pre-existing partnership | I19: "At this point, you've now got experts working together on the problem. And that happened because in this particular case HVMC had pulled this consortium together from his knowledge of the expertise needed and the companies who had both what capacity and capability both those two things of course." |
| Leadership | I13: "From a leadership position within the consortium companies, it was a way to build relationships and get to know other people and expand the network." |
| | I4: "Interestingly, the consortium was organized and led by HVMC. However, once the prototype was decided, HVMC let us to self-organize the team and solve problems without having to get their approval." |
| | I23: "Obviously, we were coordinating and collaborating with people who would normally be competitors, or we wouldn't have any contact. And so, it was a really interesting dynamic. I think we benefited from some strong leadership. HVMC were very clear upfront of the standards of professional behavior they expected from everybody and they weren't really willing to tolerate anyone going off message. So, I think it that was quite good." |
| Cognitive trust | I24: "So, in the case of ventilator challenge, the route forward was we cannot afford the time to do supplier selection and quality management around those. Those if anyone is going to join the team, they have to do it because first of all, the person at the top is trusted. And secondarily, the company itself has track record. So that that's where I came from with Ultra, so HVMC trusted me. Ultra was a well-known name in defense contracting." |
| Common vision | I11: "I call it a war effort. But it's, it is kind of a war effort, but it was like, this is absolutely the right thing to do. Nobody in Microsoft questioned whether it was the right thing to do. It was almost a case of what do they need. Let's make that happen … Faced with a major challenge, these organizations, often competitors, all had a common goal: to build at least 20 years' worth of ventilators in 12 weeks because every ventilator built has the potential to save a life." |

et al. 2020); in this case, product development was based upon Penlon's internal technologies and subsystems, alongside the collaborative efforts of the VCUK Consortium. In addition, Siemens provided digital models that facilitated immediate communication and enabled the efficient integration of the supply chain.

## 4.3 | Identification of New Themes

Following the data analysis procedure described in Section 3, the data structures were developed as Figure 2 and Tables 4 and 5, with the identification of two new theoretical themes: quasi–supply chain and re-embedding mechanisms.

### 4.3.1 | Quasi–Supply Chain

Quasi–supply chain emerged from the data as a range of distinctive technologies, patents and products, relationships, and wider experiences across various industry sectors that could be coordinated and transformed into the ventilator supply chain. A quasi–supply chain existed in a hidden fragmented form before the project and was continuously evolving and renewing during the project. Specifically, a quasi–supply chain consists of product-specific resources, general-purpose resources, and relationships and trust.

**4.3.1.1 | Product-Specific Resources.** Pertinent to this research, product-specific resources included distinctive technologies, patents, and products and knowledge that directly led to the design and production of the ventilator. For instance, Penlon combined its four *existing product subsystems* in order to develop the ventilator; Siemens Healthineers's *unique product approval experience* with MHRA was vital for the medical approval that was in compliance with the quality standard; as the interview data from Siemens indicates, "It became apparent that our medical device manufacturing knowledge was key. I think consortium members would recognize, had we not been able to comment as experts, how do you get the MHRA to approve a device? That's the experience we happen to have in Siemens Healthineers that made a difference."

Product-specific resources also refer to the professional skills required to meet *high-quality standards* in other industries that could be directly transferred to the ventilator supply chain. For example, Airbus pointed out, "The making of medical products is very close

**TABLE 5** | Codes and representative quotes of the re-embedding mechanisms.

| Axial (second-order) code/first-order code | Additional representative quotes |
|---|---|
| Behavioral re-embedding | |
| New product | I12: "We would have continued developing and producing the ESO2. The product in the VCUK is an emergency ventilator for the purpose of COVID-19 treatment. We are exploring the opportunity to further develop it." |
| | I24: "There were lots of reverse engineering the rapid prototyping during the project. This experience will be very helpful to our product development." |
| New customers | I10: "Our software certainly facilitated communication during the project, given the social distancing rule. Now we have more and more customers who want to continuously adopt the technology." |
| | I22: "I think our technologies have been proved successful during the project. So people began to approach us for new solutions of training." |
| Digital technologies adoption | I13: "We have no experience of using Microsoft technology before. Now with the use of HoloLens, some procedures have been improved. We are planning to use it for training and simulation in the future." |
| | I20: Actually, had we not had the digital tools, we would have ended up with a factory that needed many more people, a much greater risk of a COVID outbreak, a much greater risk that we couldn't have met the numbers required. There was a pivotal point where this is one of the key success factors that that technology made. |
| Cognitive re-embedding | |
| Learning | I12: "Learning from the likes of Ford, the project management team, the way things were structured in terms of meetings, in terms of the level of detail, the analytics around data and how data can really help you get back on track. And find those wins and looking for the wins because then everything looks after itself. So, agile and decision-making process within this project, would really stand Penlon in good stead going forward." |
| | I15: "What we learned from the project will help us do a better job of training people in the future." |
| Cultural change | I3: "Before VCUK, we evaluated people by performance and output. From the VCUK, we realize that to give our people a little bit goal and freedom, they can take responsibility, ownership. They now have more autonomy to do the right thing." |
| Appreciation of ecosystem | I13: "It is about change of attitudes. People now are refusing to say things can't happen." |
| | I23: "There are lots of lessons that tell us will take away around our ability to be agile, actually the motivation capability about people when we apply them something they're interested in, rather than something they've been doing probably for a fairly long period of time." |
| Relational re-embedding | |
| Reinforcing of existing relationship | I14: "We did a webinar with Microsoft together with GKN. We are working and have been working with a lot of these companies already. This was a great way to sort of reinforce our relationships. Because again, a lot of what we do, a lot of these technologies, they do rely on relationships between companies and relationships between individuals in those companies." |
| New collaborations | I13: "We are now working with STI. This is the immediate relationship after the project. They are very professional at final assembly, as demonstrated during the VCUK Project. We enjoyed working with them. In fact, we never worked with them before the VCUK." |
| | I20: "Since the VCUK Project, people began to come to us with ideas for collaboration. This includes partners from the project, whom we never have had contact before." |

(Continues)

**TABLE 5** | (Continued)

| Axial (second-order) code/first-order code | Additional representative quotes |
|---|---|
| Can-do–will-do spirit | I4: "It took many late nights and a lot of hard work, but the ingenuity and commitment of our people has been just remarkable, and it shows how a crisis can bring out the best in us." I5: "Together, we managed to meet the need from NHS. This shows how resilient we are, and we are more confident to deal with emergency together in the future." I11: "VCUK just proves that when humans come together, they can solve a problem. When you combine trust, openness, selfless teamwork, with inspiring people, and the Great British 'will-do' attitude, you can achieve the impossible." |

to aerospace. It is about people's lives. The production standards, the requirement for clean and hygienic working spaces are very similar. The overall quality and regulations are very similar."

Likewise, HVMC brought Formula One teams on board because of their *exceptional technical skills* in testing and handling emergencies, which was akin to the scenario of assembling and producing ventilators, with strict quality control requirements under urgent demand. As one Williams Racing F1 interviewee mentioned, "Formula One is all about rapid prototyping capacity. Anything you have to make, regardless of the material, regardless of the technical requirements, and even regardless of the tolerance quality, the manufacturing quality, this is something that Formula One is great at."

**4.3.1.2 | General-Purpose Resources.** Within the quasi–supply chain, there were also general-purpose resources that included a broad range of technologies, knowledge, and complementary skills, which were then applied across industry sectors. Indeed, the quasi–supply chain possessed strong *design capacity* (Penlon's medical devices design, Siemens' digital design, Formula One's prototyping skills, and Ultra Electronics' component design) and *production capacity* (Airbus and Ford). There were also *diverse skills* in testing (STI and Formula One teams) and digital communication (Microsoft). These general-purpose resources were transferable to ventilator production, serving as building blocks for the design of the reconfigurable supply chain. According to the project coordinator, HVMC, "All of us have run complicated complex businesses and have delivered complex programs, whether they be aircraft wings, motorsport programs, or cars or diesel engines."

*Managerial experience* also accounted for general-purpose resources. As noted by Airbus and Ford, their experience of coordinating complex global supply chains helped them to cope with urgent requirements during the Penlon Project. The confidence of transferring general skills and experience to the project is apparent from the interview data. For example, according to Williams Racing, "We are all highly trained personnel in technology levels … therefore, being in the mindset of being very, very careful and precise and professional when you are doing the testing or when you are doing any job."

**4.3.1.3 | Relations and Trust.** Relations and trust referred to the connections between the quasi–supply chain actors and belief in each other's competence, which led to collaborations, shared values, and the willingness to take risk. The quasi–supply chain was supported by *pre-existing relationships*. For instance, Penlon and Siemens were approached by HVMC because of their existing connection. GKN, McLaren, and Ford were existing customers of Microsoft, and Ford and Airbus brought their suppliers and subcontractors to the project. According to an interviewee from Siemens, "The reality was that we got involved because of my connection with HVMC. So, I'm a member of the supervisory board at HVMC. At the time, we didn't know what we were signing up for. Actually, we knew we had to be part of this to help do the right thing."

There was clearly strong *leadership* to coordinate the project and consolidate the relations among the quasi–supply chain partners. The UK Government played an essential part in initiating the process at the very start of the project before HVMC took the lead. Later on, four companies—Ford, Airbus, McLaren, and Siemens—acted as the key delivery partners that organized the production on a self-managed basis, without any interference from HVMC. While Ford coordinated the signing of nondisclosure agreements, the actual knowledge transfer was led by Penlon, with the technology support coming from Microsoft.

Within the quasi–supply chain, there was trust and confidence in the skills and capabilities of the project members, and this was known as *cognitive trust*. Because of this, HVMC demonstrated a determination and willingness to take risks, and this in turn facilitated collaboration across organizations freely, even though some companies were commercial competitors. There were social motivations, as organizations displayed a strong sense of civic duty to save lives by using their expertise. The quasi–supply chain was much promoted by the *common vision* to save lives as a civic duty. As Siemens emphasized, "People just wanted to help because they knew it was a time of crisis. And everyone just got to do what needs to be done to make sure that we've got enough ventilators for everybody. And our teams found that not only happened at a consortium level, but across all the suppliers."

However, there *were* also economic motivations because organizations wanted to promote their own image for marketing purposes, as well as promoting their own technologies and projects (e.g., digital tools). Consequently, organizations demonstrated a willingness to contribute, which resulted in collaboration, hence reinforcing existing relations and forming new ones for the quasi–supply chain. According to Ford, "There's no hierarchy in a time of crisis. People just work together for a common goal."

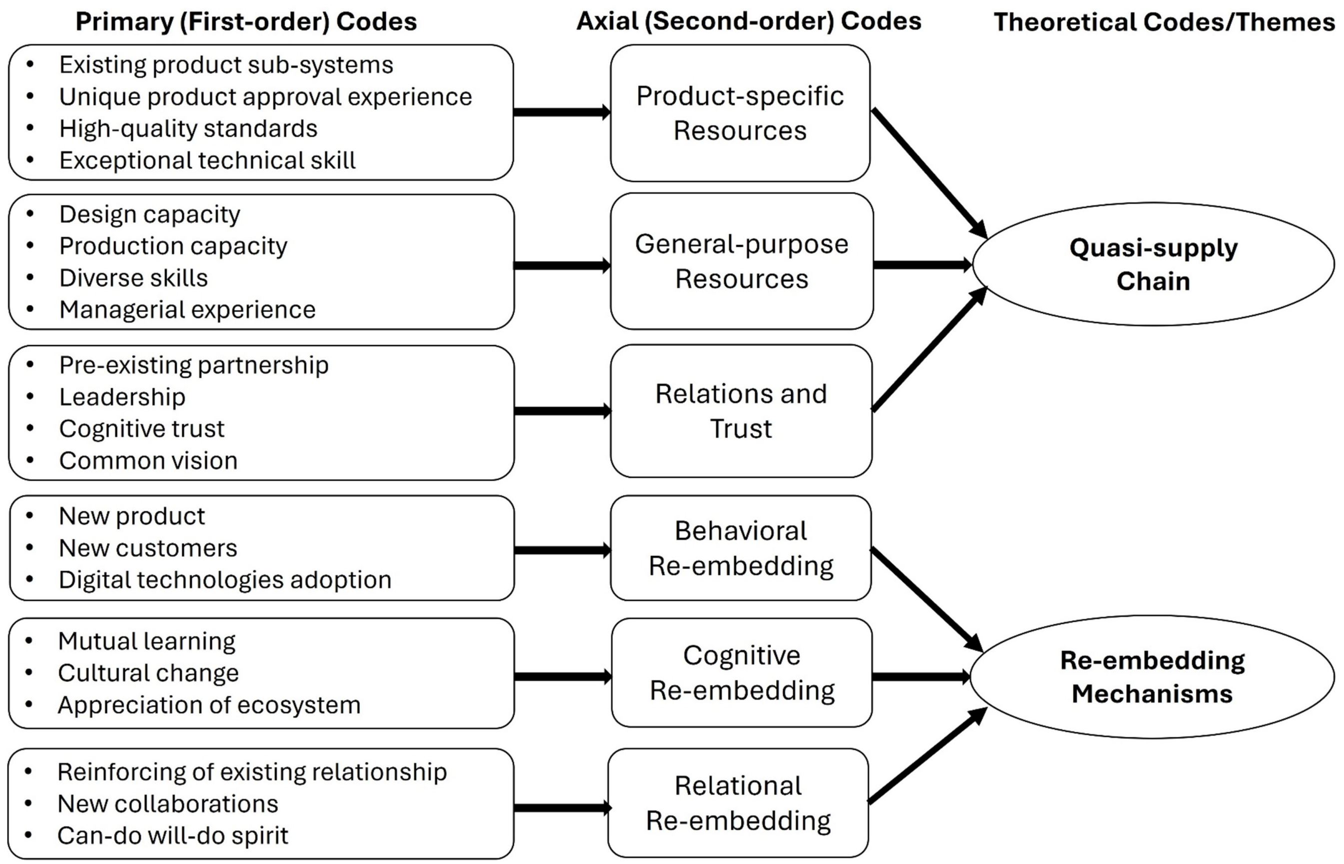


**FIGURE 2** | Data structure. [Colour figure can be viewed at wileyonlinelibrary.com]

### 4.3.2 | Re-Embedding Mechanisms

The data analysis revealed another important theme, re-embedding mechanisms, regarded as the process and interactions of returning the capabilities of the Penlon Ventilator supply chain to the quasi–supply chain upon project termination. Specifically, three types of re-embedding mechanisms were identified as behavioral, cognitive, and relational.

**4.3.2.1 | Behavioral Re-Embedding.** Behavioral re-embedding mechanisms pertain to the changes that occurred throughout the organizational practices in the forms of *new product* development, market exploration, and operational changes, which happened because of the new Penlon supply chain. For example, Penlon further developed the ventilator, seeking new market potential. As emphasized by Penlon, "we are working with experts from many fields to improve the ventilator design. In the long term, we hope this can be used beyond COVID-19 and become our new product."

In fact, the company spent 1 year on product development and received the UKCA mark in October 2021. Consequently, Penlon's ventilators have since been continuously in service with an ever-expanding clinical scope, and they are now used during many surgeries and in ICUs to tackle the backlog of semi-elective surgical procedures throughout the United Kingdom. Penlon were able to add the ventilator to their product portfolio for commercialization purposes as notable behavioral re-embedding outcomes.

As there were economic motivations to join the project, the core supply chain partners did indeed benefit economically. The effective digital design used by Siemens attracted *new customers*, and Microsoft's and Thales Training and Simulations' digital communication tools were utilized by more clients due to the effectiveness that had been demonstrated during the project. As pointed out by Siemens, "Our profile has been enhanced as potential clients came to us." Additionally, businesses prioritized *digital technology adoption* in their operations management. For example, Penlon continuously used Microsoft HoloLens for its training and simulation because of the benefits derived from the technology during the ventilator project.

**4.3.2.2 | Cognitive Re-Embedding.** Cognitive re-embedding mechanisms refer to changes in learning, culture, and how information is understood because of the new supply chain or Penlon Project. There has been continuous *mutual learning* from the project's partners, continuing even when the project had come to an end. For example, Ford and Airbus learned from Penlon's production knowledge, and Penlon captured unique process improvement skills alongside task management and data analysis processes based on Ford's car manufacturing experiences. This learning also led to an improved understanding of project management and the shaping of new methods that dealt with complexities and emergencies. According to Penlon, "In the long-term, [Ford's experience] can help improve our process such as material supply ... So what we've gained is the project management side of it. Being able to break down certain elements of a product design, the collaboration side of it."

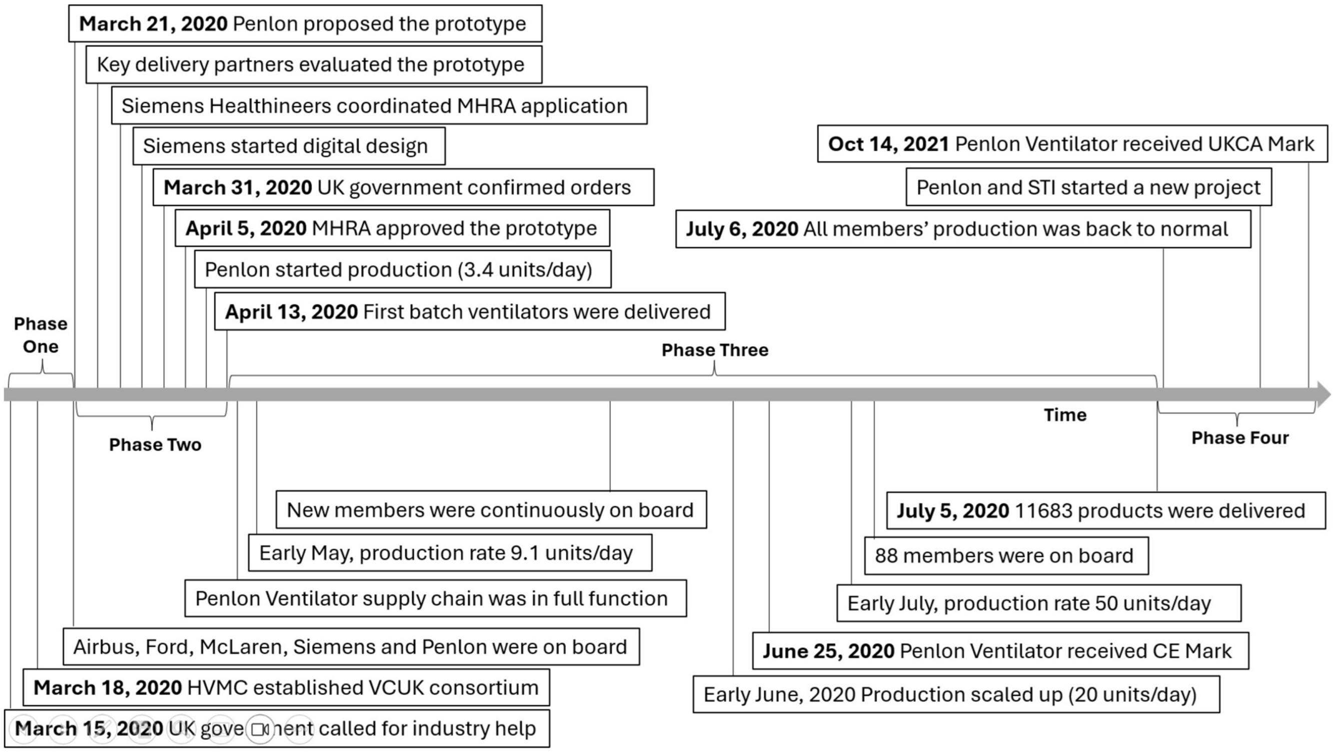


**FIGURE 3** | Key event mapping of the Penlon ESO2 Emergency Ventilator Project.

The cognitive re-embedding mechanism was also witnessed in terms of *cultural change*. For example, after the project, Airbus and Penlon adjusted both performance measurement and people management, incorporating autonomy and flexibility. It became apparent during their interviews that they had grown in confidence due to dealing with urgent requirements, by tapping into the quasi–supply chain, forging a culture of learning and sharing an increased, albeit measured, risk appetite.

Data analysis has shown an *appreciation of ecosystem* and cross-industry collaboration, which was beyond the conventional supply chains (e.g., Airbus' original supply chain in the aircraft sector). Companies realized the complementary resources from the ecosystem could be utilized for further product development. As a Microsoft interviewee pointed out, "Partners are going to develop a product and they claim they know their industry, but there's always going to be things that they don't know about the industry that someone will turn around and say, well, this would be a really good capability to have. Yeah. So, I think working with partners to help develop capabilities on the platform would be how that can be accelerated."

Even for Airbus, there was a cognition toward working with other industries. As Airbus said "We don't know everything, and we used to think we do. Now the experience of working with Siemens told us it is ok to look outside. They were really competent and good people ... we can rely on others and learn from people."

**4.3.2.3** | **Relational Re-Embedding.** The relational re-embedding mechanism refers to the strengthening and reintegration of existing relationships, and the development of new relationships from the supply chain. For example, Microsoft, Ford, PCT, GKN, and Ultra Electronics have *reinforced the existing relationship* with their existing suppliers and customers who were also active in the project. As PTC said, "We are working and have been working with a lot of these companies already. This was a great way to sort of reinforce our relationships."

HVMC, as the leader and initiator of the project, extended its network from West Midlands–based manufacturing companies to 88 UK-wide organizations across various sectors. A relational re-embedding mechanism was also seen in the form of *new collaborations*. Just a few months after the ending of the Penlon Project, Penlon and STI jointly collaborated upon another medical product development project, and they had never worked together before the Penlon Project. Also, Penlon approached a range of individuals and organizations, such as clinical specialists, analysts, MD-TEC lab, NHS, DHSC, and SGS UK, to further develop the ventilator product.

In a broader sense, there was a resurgence of vigor across the Penlon Project's partners, with fresh determination, energy, ingenuity, common vision, and a *can-do–will-do spirit*, leading to their belief in the success of further collaborative projects. This was emphasized by the project leader of HVMC and members, for example, as "trust, openness, selfless teamwork, with inspiring people, and the Great British 'will-do' attitude" by Microsoft and "teamwork, energy, resolve, ingenuity and, most of all, bravery of everyone" by McLaren.

## 4.4 | A Theoretical Model

To elaborate upon the connections among the themes, a theoretical process model was generated (see Figure 5), with the relationships highlighted as A, B, C, D, A1, and A2.

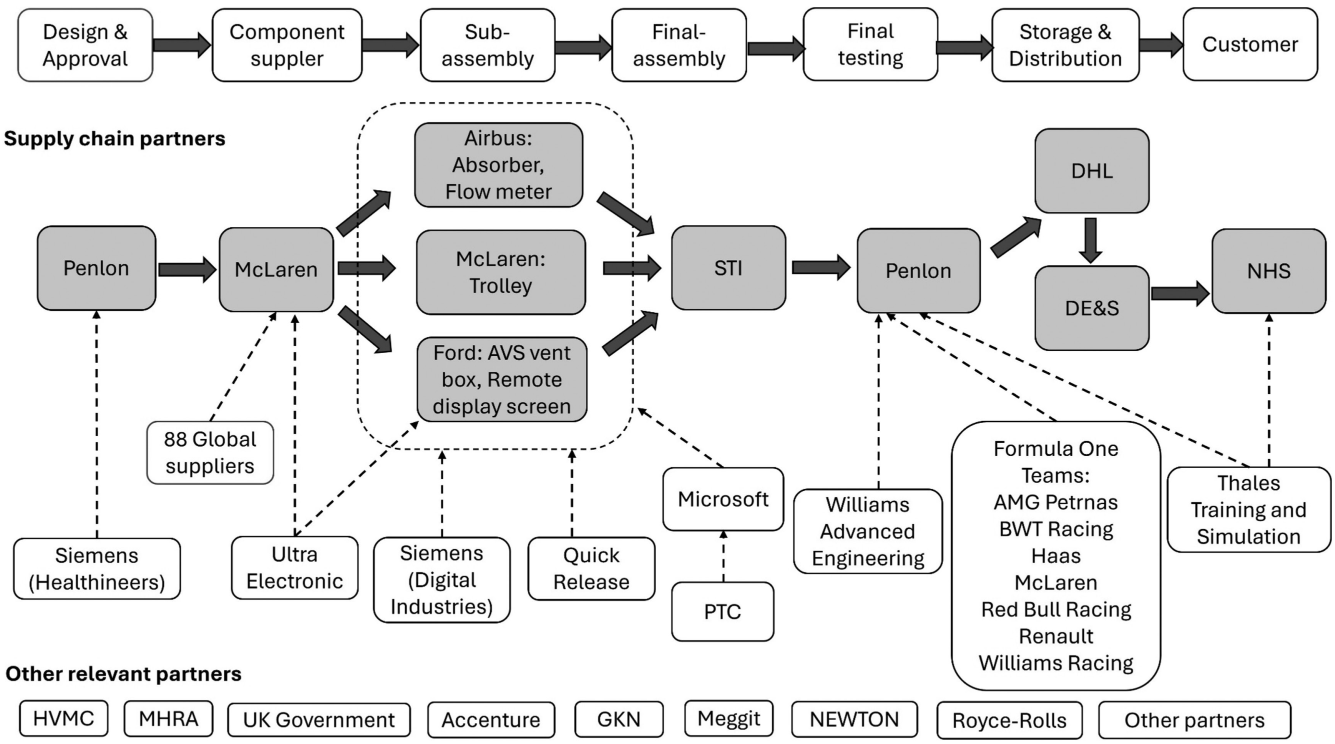


**FIGURE 4** | Structure of Penlon ESO2 Emergency Ventilator Supply Chain.

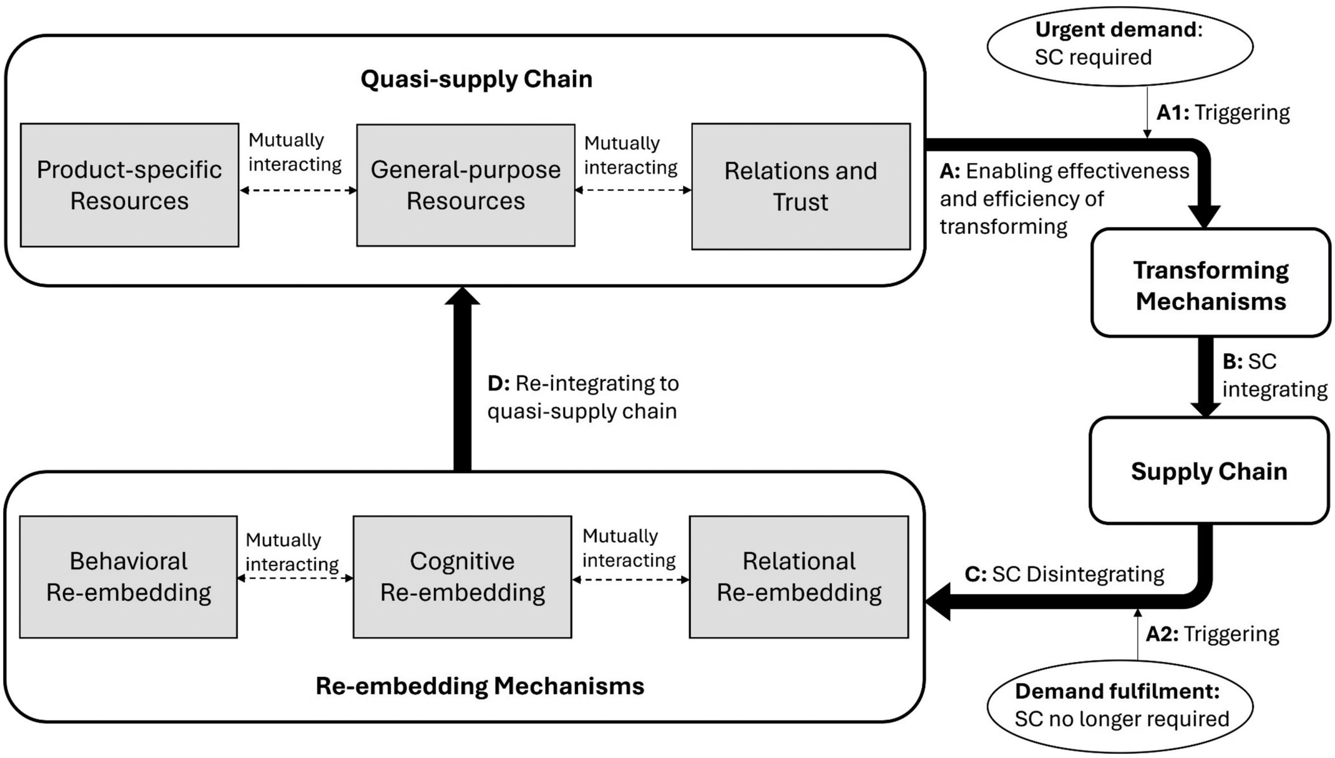


**FIGURE 5** | A theoretical model of transformative supply chain management process from an ecosystem perspective.

The model begins with the pre-existence of a quasi–supply chain that builds upon resources and connections among organizations. It was inactive until triggered by the urgent demand for new products and new supply chains (A1). Within the quasi–supply chain, product-specific resources—distinctive technologies, patents, products, and quality assurance systems that directly led to the product design and production—immediately resulted in product development as an important part of transformation mechanism (A). General-purpose resources, such as design, production, assembly, and testing

**TABLE 6** | A comparison of quasi–supply chain and supply chain.

| | Quasi–supply chain | Supply chain |
|---|---|---|
| Context | • Operating under a highly uncertain, urgent, and transformative condition<br>• Demand is unpredictable<br>• The product can be new and unclear | • Operating under a normal condition with a relatively stable set of suppliers<br>• Demand can be predictable<br>• The product is well defined |
| Construct | • A range of technologies, skills, experiences, and relations<br>• Resources across industry boundary<br>• The collaboration can be informal | • The core company's and upstream and downstream partners' resources<br>• Resources in the same industry<br>• Formal contract and collaboration |
| Capability | • Be able to form a new supply chain in response to disruptions and crisis<br>• High effectiveness and efficiency<br>• High adaptability, agility, and resilience to cope with huge disruptions | • To optimize existing products and processes<br>• High effectiveness and efficiency<br>• Adaptability to cope with normal disruption |

skills applied across industry sector and transferred to supply chain integration (A).

As an element of quasi–supply chain, existing relations with suppliers, industry connections, and trust in partners' competence provide support to supply chain integration (A). Trust enables successful supply chain relationships and positively affects supply chain performance (Terpend and Ashenbaum 2012). Specifically, cognitive-based trust is built on logical assessment and leads to behavioral trust and risk taking (Suh and Kwon 2006), as quasi–supply chain partners are committed to a project based upon understanding the skills and competence of others. Consequently, the three elements of the quasi–supply chain are mutually supported and jointly assisted the transforming mechanisms; the richness, diversity, and breadth of the quasi–supply chain enabled the efficiency and effectiveness of the transforming mechanisms (A).

Further, the transforming mechanisms process fragmented resources from the quasi–supply chain and fully integrated them into a supply chain (B). This supply chain not only meets short-term demand, but alongside this disintegration due to demand fulfillment (A2), the sustained capabilities, such as the orchestration of complexity and the resilience and responsiveness to cope with changes, are stored before being returned to the quasi–supply chain through the functions of re-embedding mechanisms (C).

Finally, the re-embedding mechanisms reintegrate the capabilities into the quasi–supply chain (D). Specifically, new product-related behavioral re-embedding mechanisms directly led to the enhancement of product-specific resources (D). Indeed, such behavioral re-embedding is similar to entrepreneurial embeddedness in supply chain literature, meaning the degree by which a large organization integrates small entrepreneurial business capabilities (e.g., creativity and rapid decision-making) within its supply chain (Ketchen and Craighead 2021). However, the re-embedding mechanisms here also include a range of organizational changes that improve general-purpose resources in the forms of both better design and production performance (D).

Cognitive re-embedding mechanisms enable organizations to appreciate ecosystems and trust other organizations' skills (D). Specifically, because an organization's performance depends on how they engage with suppliers and customers (Choi and Kim 2008), they are embedded in a network of interdependency (Shipilov and Gawer 2020), namely, a quasi–supply chain that is built upon interorganization relationship and trust.

Relational re-embedding mechanisms concern attitudes, values, and norms that affect organizations and people (D). This is based upon the belief that networks are shaped by relational embeddedness processes through repeated partners or ties between new suppliers or partners (Skilton et al. 2020).

It is also evident that these three re-embedding mechanisms interact with one another. For example, alongside the behaviors of a company's new product development projects, cognitively, the importance of collaboration beyond conventional supply chains is realized, and in turn, new relationships are developed. Thus, transpiring simultaneously, the behavioral, cognitive, and relational re-embedding mechanisms reintegrate the supply chain into the quasi–supply chain with both resource enrichment and capability upgrading (D).

As shown in Figure 5, the theoretical model demonstrates the relationships among the themes. It also shows that, under extreme conditions, the surge demand may not rely on an existing supply chain. Instead, this dynamic and iterative process represents an ecosystem perspective, where fragmented resources within the quasi–supply chain across industry boundaries are integrated toward a supply chain, and the supply chain can be further reintegrated into the quasi–supply chain. This will also prepare us for the next round of transformation toward another supply chain should there be a new urgent demand; thus, the model represents a closed loop.

## 5 | Discussions and Conclusions

### 5.1 | Theoretical Contributions

#### 5.1.1 | Comparing a Quasi–Supply Chain With a Supply Chain

An important concept identified from examining the supply chain transformation from an ecosystem perspective is the quasi–supply chain, which refers to a range of product-specific resources (e.g., distinctive technologies and patents), general-purpose resources (e.g., skills and competence and components spanning various industry sectors), and relations and trust (e.g., interorganizational relationships), which can be coordinated and transformed toward a new supply chain in response to extreme conditions. The two concepts are compared (Table 6) in terms of the context (environmental factors and industry settings), construct (structural elements and building blocks), and capability (functional success features), by using the framework applied to both supply chain and ecosystem research (Rong et al. 2015; Zhang, Gregory, and Shi 2007).

As highlighted in Table 6, while supply chains operate under normal conditions to deliver well-defined products with high efficiency and effectiveness, a quasi–supply chain operates within a highly dynamic and unpredictable environment (Sodhi and Tang 2021; Wieland 2021). Actors throughout the quasi–supply chain can change their role, as the case study reveals, alongside the evolution of the quasi–supply chain toward a supply chain. This can be linked to the evolution perspective of an ecosystem (Shi, Liang, and Luo 2023). It is also noted that the quasi–supply chain can be self-organized, sometimes without a focal firm. In fact, the identification of a quasi–supply chain, which exists before the formation of a supply chain and even after the supply chain is dissolved, answers a recent call for research on the adaptive and integrated approaches to operating supply chains (Wieland 2021).

The concept of the quasi–supply chain includes a wide range of resources, internally and externally. A supply chain consists of resources from the focal company and its upstream and downstream partners, normally from within the same industry. However, resources of a quasi–supply chain can be more diverse, including those from other industry sectors, and sometimes, there can be changing of the core companies within the quasi–supply chain, as seen from the case study. Product-specific resources in the quasi–supply chain can be linked to the resource-based view to utilize network resources to produce a continuous stream of new products (Henard and McFadyen 2012; Lavie 2006). General-purpose resources, on the other hand, can be seen as complementary resources that contribute to the value creation of an ecosystem, surpassing industry boundaries (Shi, Liang, and Luo 2023; Shi and Shi 2022).

In terms of capability, similar to supply chains, quasi–supply chains deploy high efficiency and effectiveness (Ellram, Tate, and Feitzinger 2013). However, the quasi–supply chain specifically aims to perform to a high standard of capabilities in order to coordinate and transform toward a new supply chain that can cope with an ever-changing environment with varying degrees of supply and demand volatility. Thus, in comparison to a supply chain, a quasi–supply chain deploys much higher adaptability and agility, as well as a resilience to cope with huge disruption.

#### 5.1.2 | An Ecosystem Perspective to Supply Chain Management Under Extreme Conditions

Despite numerous useful insights into the normal conditions of supply chain management, supply chain management under extreme conditions is often eluded in extant literature (Sodhi and Tang 2021). These extreme conditions may stem from disruptions that are difficult to predict and prepare for and that have global impacts upon supply chains (Sodhi and Tang 2021); to give examples, disruptions such as pandemics, the climate change, and geopolitical conflicts. Under such circumstances, the traditional "static and reductionist" view of supply chain management may no longer hold, as uncertainty in both supply and demand increases dramatically (Wieland 2021; Wieland and Durach 2021). In the Penlon Project, the uncertainty regarding the demand for ventilators was high, but supply availability of various components was extremely low.

The findings therefore offer new insights into the process of transformative supply chain management from an ecosystem perspective, utilizing new sets of suppliers who are usually outside the sector of the emergent, ex post product, which thus requires distant resources beyond the realm of existing supply chains (Shen and Sun 2023). Further, this research shows how supply chain management for extreme conditions may also take place in a collective manner among various organizations. In contrast, the extant literature often addresses how a single, focal firm determines supply chain design (Beamon 1998; Meixell and Gargeya 2005).

Specifically, such an ecosystem perspective to transformative supply chain management unfolds in two complementary mechanisms: (1) the transformation mechanism by which organizations leverage a quasi–supply chain to enhance the reconfigurability of the supply chain and (2) the re-embedding mechanism that delineates the process of the dissolution of the newly established supply chain, which, in turn, enriches the quasi–supply chain.

While the transformation mechanism is reminiscent of recent studies undertaken on supply chain management that engage external resources (Abushaikha, Wu, and Khoury 2021; Shen and Sun 2023), the re-embedding mechanism represents the other key, yet poorly understood, underpinning of successful supply chain management for extreme conditions by demonstrating the feedback impacts on the external resources (quasi–supply chain) per se. In this sense, this research contributes to the emerging transformative supply chain management research (Mollenkopf et al. 2024) that goes beyond traditional supply chain management under normal conditions.

Finally, the transformation and re-embedding mechanisms delineate the processes of transformative supply chain management. Such mechanisms are particularly critical in coping with megadisruptions that render existing suppliers unavailable and prompt the need for novel products that require distant resources outside of an organizations' prior sectors, which also contextualizes the *stand-by capabilities* (Bendoly and Tang 2021) and the *preparedness* of supply chains in extant supply chain resilience literature (Kovács and Falagara 2021).

### 5.2 | Managerial and Societal Implications

For supply chain managers, the model offers processual guidance on how they could be better prepared for extreme conditions by nurturing a quasi–supply chain within an ecosystem that delivers novel products that emerge ex post. Further, the ecosystem perspective to supply chain transformation also enables managers to gain a broader perspective when dealing with large-scale disruptions where demand uncertainties are high and supply availability is extremely limited. Such implications go beyond pandemics but may also include future extreme conditions where the consequences may have major global impacts; to give examples, geopolitical conflicts involving major world powers and leading to widespread humanitarian disasters that affect trade, economies and global stability (Abushaikha, Wu, and Khoury 2021), or the climate crisis that results in more extreme weather events and rising sea levels (Azadegan and Dooley 2021).

The findings also inform policymakers and the broader public on how to better facilitate the formation of a quasi–supply chain by setting up various cross-industry consortiums. These consortiums may encompass key players across various local industries and in different technological interfaces, which in turn may serve to enhance the reciprocities between the existing supply chain and the wider ecosystem. Such interactions can be supported by delicately designed policy instruments that will encourage transformation and re-embedding mechanisms across the different members of the consortiums and their existing supply chains.

### 5.3 | Limitations and Future Research

This study has combined Gioia's (Gioia, Corley, and Hamilton 2013) approach to identify theoretical concepts in a systematic and transparent way and process theory (Langley et al. 2013) to elaborate the temporal dynamics among the concepts. Although the method goes beyond a traditional "template," there are still limitations that also offer future research opportunities.

While the nature of process-related qualitative research can help illustrate more textures in mechanisms (Chen, Dooley, and Rungtusanatham 2016), it has relatively low generality (Chen, Dooley, and Rungtusanatham 2016; Langley et al. 2013), in comparison to traditional empirical studies. Also, as the process analysis mainly focused on the VCUK consortium-level events, future research could zoom into events transpired at the organizational level, for example, how, when, and why an organization decided to join or leave the project, as well as how they coordinated the Penlon Project within their original supply chains which were not fully captured in this study.

Second, although the research strives to improve "transferability" (Gioia, Corley, and Hamilton 2013) of the ecosystem perspective to supply chain transformation in similar settings, the extent to which these findings can be applied to a commercial environment needs to be further elaborated upon, as the case study was conducted amid a national crisis where a large portion of the liabilities and financial risks were with the government.

Third, such an ecosystem perspective is likely to be more feasible when the support of a powerful focal player (that may or may not be a government) is readily available to coordinate players across multiple industries. In this case, the UK government helped set up the VCUK Consortium to mobilize resources that would have been an impossible undertaking for an individual organization. Future research could examine how such a transformation process unfolds when powerful focal players are absent.

Finally, the ecosystem perspective may be more effective when the quasi–supply chain shares technological modularity and complementarity with the existing supply chain. In this case, automobile and digital tool suppliers, although not previously involved in the production of medical devices, contribute complementary capabilities and transferable modules to the ventilator production. Future research could explore how emerging technologies that are highly specialized within the supply chain may influence the transformative supply chain management.

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