

Resilience in Healthcare Supply Chains: A Review of the UK's Response to the COVID19 Pandemic

Abstract

Purpose: This explorative research analyses the resilience of the United Kingdom's (UK) healthcare supply chains from a customer's perspective in the light of the coronavirus pandemic.

Design/methodology/approach: Using the capabilities of preparedness, robustness, recovery and adaptability as the foundational percept for supply chain resilience, 22 healthcare professionals in 17 of the UK's National Health Scheme (NHS) Trusts were interviewed to explore their personal and organisational approaches adopted relative to the provision of eye protection, gloves, gowns, aprons, masks and respirators. The Dynamic Capabilities View is mapped unto the resilience capabilities and used to analyse the data from a transformational supply chain research perspective.

Findings: That the supply chains were largely unprepared was not particularly surprising even though availability of gloves were significantly better compared to the other PPE. Techniques adopted to ensure robustness and recovery revealed the use of unsanctioned methods such as extended use of PPE beyond recommended use, redefinition of guidelines, protocols and procedures by Infection Control and the use of expired PPE – all of which compromised customer well-being.

Practical Implications: The compromise of the well-being of healthcare workers due to the vulnerabilities of healthcare supply chains is highlighted to managers and recommendations for post-disruption adaptability are made.

Originality/value: This paper introduces transformative research to supply chain resilience research by uniquely looking at resilience from the customers' well-being perspective.

Limitations: As the paper views resilience through the lens of customers, it does not provide the perspectives of the supply chain practitioners as to the reasons for the findings and the challenges within these supply chains.

Keywords: Supply chain resilience, Dynamic Capabilities, Personal protection equipment, Healthcare supply chains, COVID19 pandemic, Transformative supply chain research

Article Classification: Research paper

1. Introduction

Since the very first case of the novel coronavirus, COVID-19 was confirmed in Wuhan, China late 2019 (The Novel Coronavirus Pneumonia Emergency Response Epidemiology Team, 2020), the effects of the rapid rate of its spread has provided further support to the increased global vulnerability of supply chains to disruptions. After just a few months since the confirmation of the first case, global cases quickly rose to 2.4 million in over 185 countries and territories as of mid-April 2020 (CSSE, 2020). Even though many organisations may insist they have plans in place, when disruption occurs, they typically find that they were inadequately prepared (VanVactor, 2011). The unpreparedness observed in many organisations was evident in many global supply chains as well (Ivanov, 2020a; Queiroz *et al.*, 2020) and the effects have been unprecedented (Ivanov and Dolgui, 2020). Considering Wuhan alone, over 50,000 companies worldwide suffered disruption to their first-tier suppliers while over 5 million were affected when second-tier suppliers were considered (Dun and Bradstreet, 2020; Ivanov, 2020b; Queiroz *et al.*, 2020).

The effects of COVID19 were particularly evident in healthcare supply chains. These supply chains are important for human welfare and the span and quality of life of patients (Graves *et al.*, 2009). They do not only provide the medication and equipment used by patients; they also facilitate the provision of the equipment used by healthcare professionals to deliver services. Thus, the importance of healthcare supply chains become particularly heightened in the face of major disasters that result in spikes in demand as well as supply shortages for healthcare equipment. Therefore, the capability of supply chains to effectively prepare, absorb and/or resist, recover from and adapt to the COVID19 pandemic and its concomitant disruptions necessitate a closer look at the resilience of healthcare supply chains.

Many healthcare supply chains failed during the COVID19 pandemic and this is most evident in the strain on the provision of Personal Protective Equipment (PPE) (WHO, 2020a) as demands were not met. The implications of this failure on healthcare personnel were dire. The high rates of infection and death of healthcare professionals and patients in Italy were partly attributed to inadequate access to PPEs (Burki, 2020; Ranney *et al.*, 2020). In the US, the Centres for Disease Control and Prevention recommended restricted access to PPEs and reuse of otherwise single-use PPEs. The resulting pressures caused some healthcare professionals to resort to using scarves and bandanas and individual purchases of

PPEs (Mehrotra *et al.*, 2020; Ranney *et al.*, 2020). To deal with their high levels of shortages, the healthcare industry in the Republic of Ireland resorted to a variety of measures including bespoke production of PPEs and high-level disinfection for PPE reprocessing (Rowan and Laffey, 2020). In all of these, the vulnerabilities of healthcare supply chains had compromised the health and safety – thus, the well-being of the healthcare professionals. Consequently, the need for resilience in healthcare supply chains should not only be to address demand spikes and supply shortages but perhaps even more importantly, the well-being of the customers (Aldrighetti *et al.*, 2019). This reveals the urgent need to incorporate transformative supply chain research (TSCR) into the study of healthcare supply chain resilience. Mollenkopf *et al.* (2021), using a TSCR perspective, examined employees and customers' well-being within food supply chains during the coronavirus pandemic. The paper highlighted the increasing responsibility of food supply managers to see to the health and safety of employees and customers while in store as a desirable well-being outcome and called for further research employing a transformative lens. TSCR draws from the transformative consumer research and transformative service research literature (Mick, 2006; Pettigrew *et al.*, 2014; Rosenbaum, 2015), which challenges researchers to focus on enhancing the well-being of individuals and communities. Well-being is defined by Mick *et al.* (2012, p. 6) as “*a state of flourishing that involves health, happiness and prosperity*”.

This transformative research seeks to analyse the resilience of healthcare supply chains to disruptions and the implications of these on the well-being of the customers of these chains by answering the following research questions:

1. How prepared were the healthcare supply chains for the COVID19 disruptions?
2. How did healthcare supply chains cope, resist and/or recover from the COVID19 related disruptions?
3. How can healthcare supply chains be better positioned to deal with global disruptions to ensure the well-being of their customers?

To answer these questions, this study conducted interviews with the customers of healthcare supply chains in the UK to capture their experiences with the provision of PPEs and the actions they took and/or were

required to take to accommodate the unavailability of these equipment. These actions are then compared with the World Health Organisation's guidelines on the prevention and control of infections during a pandemic. These were then analysed using a Dynamic Capabilities View (DCV) lens of supply chain resilience capabilities as identified in literature. A transformative supply chain resilience positioning – due to the collection of data from the customers of the supply chain, allowed for the effects of the actions taken under each resilience capability on their well-being to be discussed. By this, we make recommendations on the development of dynamic capabilities that will allow healthcare supply chains to adapt from the disruptions suffered for improved resilience, not only to ensure adequate PPE provisioning but to seriously consider the well-being of healthcare professionals in so doing.

The rest of the paper is organised as follows. A literature review of resilience in healthcare supply chains and dynamic capabilities theory is presented. This is followed by a discussion of the methods for data collection and analysis. The findings and analysis are provided and recommendations for developing dynamic capabilities for adaptability post-COVID disruptions are made. The research, practical and policy implications are then discussed and the limitations and directions for future research are indicated to conclude the paper.

2. Literature Review

2.1 Resilience in Healthcare Supply Chains

Interest in healthcare supply chain management research has gradually heightened over time with some of the most researched topics being in the areas of information technology and new technology in services and design of service delivery systems, capacity planning, scheduling and control (Dobrzykowski *et al.*, 2014). Like humanitarian aid supply chain management, healthcare supply chain management differs from commercial supply chain management because healthcare is a specialised industry that needs to be prepared for instances beyond the unexpected within 'normal' supply chain operations such as large-scale sickness outbreaks, chemical/biological attacks and pandemics (VanVactor, 2011). Since flows in these supply chains are of high criticality, service levels must be very high and thus, standard supply chain

management practices may not always be applicable (Aldrighetti *et al.*, 2019; de Vries and Huijsman, 2011). Furthermore, the supply chains here are characterised by high levels of complexity, the movement of highly valuable goods and most importantly because they involve human lives (Aldrighetti *et al.*, 2019). For this reason, some inefficiencies that are generally intolerable in other supply chains, such as the maintenance of unusually high levels of stock, are acceptable in these supply chains as human life is valued above service levels. Nevertheless, supply chain costs here have been identified to cost as much as 30% of a hospital's operating budget, thereby making prudent supply chain management an important opportunity for cost savings (Zepeda *et al.*, 2016).

These supply chains have therefore not been spared the increasing pressure to be as lean as practically possible while improving the quality and consistency of service delivery to customers (Battini *et al.*, 2013). Besides the bullwhip effect, which results from challenges in the procurement and delivery of medical equipment (Jafarnejad *et al.*, 2019), non-availability of supply, global sourcing and increased outsourcing have rendered these supply chains longer and more complex, with reduced visibility (Graves *et al.*, 2009; VanVactor, 2011). Healthcare supply chains have therefore become more vulnerable to disruptions. With the increasing impact of disasters on human lives in recent times (Jabbarzadeh *et al.*, 2016; Snyder *et al.*, 2016), the need for resilience in healthcare supply chains has been established as extremely critical (Aldrighetti *et al.*, 2019; Bag *et al.*, 2019; Graves *et al.*, 2009; Mandal, 2017) as these not only increase the service demand of the supply chains but they also upset the continuity of healthcare service delivery.

Supply chain resilience has been defined as “*the ability to proactively plan and design the supply chain network for anticipating unexpected disruptive (negative) events, respond adaptively to disruptions while maintaining control over structure and function and transcending to a post-event robust state of operations, if possible, more favourable than the one prior to the event, thus gaining competitive advantage*” (Ponis and Koronis, 2012, pp. 925–926). For healthcare supply chains, this would require the synchronisation and integration of the resources and capabilities of supply chain entities to ensure adequate preparedness, effective recovery and response, but most importantly, robust service delivery to healthcare workers and patients in the event of a disruption (Mandal, 2017). However, these supply chains also ought to support the well-being of its customers.

2.2 Supply Chain Research and Well-being

Seeking to transform the field of consumer research into a relevant and impactful discipline, Mick (2006) presented “transformative consumer research” (TCR) as a research domain that sought to highlight consumer welfare through focus on research topics such as vulnerable consumer groups, nutrition and obesity, financial and medical decision making, product safety and environmentally protective behaviours, among others. Over time, transformative research, particularly within the marketing discipline, would refer to research that, beyond its methodological rigorousness in informing theory, also contributed to the well-being of individuals and communities and disseminates the findings to relevant stakeholders (Mick *et al.*, 2012).

The concept traversed the borders of the marketing discipline into management studies as transformative service research (TSR) as introduced by Anderson (2010). Here, the discipline investigates the relationship between service and well-being by focusing on creating uplifting changes that aims to improve the lives of individuals (both consumers and employees), families, communities, society and the overall ecosystem (Anderson *et al.*, 2013; Anderson and Ostrom, 2015). The indicators of well-being here included metrics such as mental health, physical health, discrimination, literacy, inclusion, marginalisation, capacity building, financial well-being and reduced disparity among others (Anderson *et al.*, 2013; Anderson and Ostrom, 2015; Rosenbaum, 2015; Rosenbaum *et al.*, 2011). Fundamentally, transformative research seeks to impact individual and communal well-being, whereby well-being refers to a state of flourishing involving health, happiness and prosperity (Mick *et al.*, 2012).

From a supply chain perspective, the value that is delivered to the ultimate consumer has been viewed “*in the form of products and services*” (Christopher, 2011, p. 13). The effective management of the supply chain has thus been proved to lead to superior value creation, customer satisfaction, and customer retention (Heckmann *et al.*, 2015; Lee, 2002). However, an important role supply chains play in value provision to end users have been the contribution to individual and community well-being. The effects of the many supply chain disruptions caused by the COVID19 pandemic made this particularly obvious. This thereby presents an invigorating research stream within supply chain management studies that

explores its transformative nature in addressing well-being. Mollenkopf *et al.* (2021) calls this research domain “transformative supply chain research”. The relevance of TSCR is particularly heightened in healthcare supply chains, considering their uniqueness, criticality and impact on human well-being in terms of physical and mental health.

Thus, the capabilities required in healthcare supply chains, should not only lead to efficiency, effectiveness and resiliency, but must also ensure the well-being of customers. The Dynamic Capabilities View offers an insightful theoretical lens through which these capabilities can be discussed.

2.3 Dynamic Capabilities

The Resource-Based View (RBV) highlights the need for organisations to develop capabilities through the possession, integration and management of valuable, rare, inimitable, and non-substitutable (VRIN) resources to surmount difficulties and gain competitive advantage (Barney, 1991; Eisenhardt and Martin, 2000; Wernerfelt, 1984). The theory has however been criticised for not presenting a sufficient condition for sustainable competitive advantage as is claimed (Eisenhardt and Martin, 2000; Fawcett *et al.*, 2011) because it fails to properly delineate capabilities when dynamic changes occur in uncertain environments (Chowdhury and Quaddus, 2017). To address this, Teece and Pisano (1994) introduced the Dynamic Capabilities perspective, which is an extension of the RBV in dynamic markets where there is “*rapid and unpredictable change*” (Eisenhardt and Martin, 2000, p. 1106). Dynamic capability was subsequently defined as “*the firm’s ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments*” (Teece *et al.*, 1997, p. 516). This definition thereby introduced an adaptability dimension, in terms of the organisation’s ability to attain new and innovative forms of competitive advantage by the alignment of internal and external resources (Modgil *et al.*, 2021; Teece *et al.*, 1997).

Teece *et al.* (1997) referred to ‘dynamic’ as the capacity to renew competencies to achieve congruence with the changing environment while ‘capabilities’ emphasise the strategic management’s key role in appropriately adapting, integrating and reconfiguring both internal and external organisational resources,

skills and functional competences to match the demands of the changing environment. A firm's capabilities are developed from the integration and coordination of its resources (Modgil *et al.*, 2021; Ponomarov, 2012). Thus, firms are expected to reconfigure and renew internal and external resources proactively and reactively within the highly dynamic environment to develop the dynamic capabilities requisite for adaptability, longevity and competitive advantage (Eisenhardt and Martin, 2000; Hendry *et al.*, 2019; Modgil *et al.*, 2021; Mwangola, 2018; Teece *et al.*, 1997).

Some authors (such as Brusset and Teller, 2017; Cepeda and Vera, 2007; Helfat and Peteraf, 2003; Mwangola, 2018) have found the need to differentiate between operational capabilities and higher-order capabilities as fundamental to the concept of dynamic capabilities. Operational capabilities have been described as responsible for a firm's daily routines and directly contribute to the firm's output while higher-order capabilities contribute indirectly through their impact on operational capabilities (Mwangola, 2018). From this distinction, dynamic capabilities have been identified as higher-order capabilities as they are a learned pattern of collective activities and strategic routines that indirectly contribute to an organisation's performance and sustained competitive advantage by targeting the generation and modification of a firm's resources and operational practices (Brusset and Teller, 2017; Drnevich and Kriauciunas, 2011; Mwangola, 2018; Teece *et al.*, 1997; Zollo and Winter, 2002; Zott, 2003).

Brusset and Teller (2017) argued resilience as an operational capability that requires both internal processes as well as information flow, coordination and collaborative processes with upstream and downstream partners. However, they considered this operational capability as a high-level routine, thereby realigning it with the more common conceptualisation of resilience as a higher-order capability and more specifically, a dynamic capability (Eltantawy, 2016; Hendry *et al.*, 2019). From this perspective, the attainment of competitive advantage transcends an organisation's boundaries to include the efficient and effective sharing and deployment of resources between actors within the supply chain (Rajaguru and Matanda, 2013). Consequently, the DCV can serve as a useful lens in addressing large scale disruptions (such as COVID19) and in seeking means to improve the resilience of supply chains (Chowdhury and Quaddus, 2017; Kwak *et al.*, 2018).

2.4 Dynamic Capabilities and Supply Chain Resilience

The DCV has had its fair share of criticisms, including challenges with definition (Hendry *et al.*, 2019), obscure (Gebauer, 2011), pleonastic and lack of empirical grounding (Chowdhury and Quaddus, 2017; Eisenhardt and Martin, 2000). Notwithstanding, Teece (2007), seeking to strengthen the theory's analytical potency indicates that dynamic capabilities can be broken down into the capacity "*to sense and shape opportunities and threats, to seize opportunities, and to maintain competitiveness through enhancing, combining, protecting and when necessary, reconfiguring the business enterprise's intangible and tangible assets*" (Teece, 2007, p. 1319). As highlighted by Hendry *et al.* (2019) and Mwangola (2018), this conceptualisation of DC reveals theoretical similarities with the understanding of SCR capabilities provided in literature (Ali *et al.*, 2017; Ponis and Koronis, 2012; Ponomarov and Holcomb, 2009; Sawyerr and Harrison, 2020). Unsurprisingly, many researchers (such as Chowdhury and Quaddus, 2017; Eltantawy, 2016; Hendry *et al.*, 2019; Modgil *et al.*, 2021; Mwangola, 2018; Ponomarov, 2012) have applied DCV within an SCR context.

There are generally four resilience capabilities identifiable in SCR definitions provided in extant literature. These are preparation or readiness, robustness, recovery and adaptability (Ali *et al.*, 2017; Pereira *et al.*, 2020; Sawyerr and Harrison, 2020). The preparation capability encapsulates a supply chain's ability to anticipate disruptions by monitoring for triggers and changes and understanding their probabilities and potential impacts to avoid them or mitigate against them (Ambulkar *et al.*, 2015; Carvalho *et al.*, 2012; Datta, 2017; Hohenstein *et al.*, 2015; Ponis and Koronis, 2012; Ponomarov, 2012; Ponomarov and Holcomb, 2009; Tukamuhabwa *et al.*, 2015). This capability is proactive and requires the supply chain to be able to not only avoid and withstand disruptions but also to equip the supply chain to quickly recover from disruption (Kamalahmadi and Parast, 2016). This perspective aligns with Teece's (2007) first capability of DC to sense and shape opportunities and threats, which relates to the capacity of a firm to assess and leverage the business environment's information and to exploit the capabilities of supply chain actors such as suppliers and customers (Mwangola, 2018).

Robustness refers to the ability to resist, cope with or withstand the disruption or its effects by maintaining a desirable level of performance (Adobor and McMullen, 2018; Pereira, 2009; Ponomarov and

Holcomb, 2009; Schmitt and Singh, 2012; Zavala-Alcívar *et al.*, 2020). Some disruptions are unavoidable and overcome a supply chain's capability to cope or resist. This capability allows the supply chain to react in a timely and efficient manner, maintain control and retain structure (Ali *et al.*, 2017) by strategies such as postponement, strategic stock, flexible supply base and flexible transportation (Tang, 2006). These allow the supply chain to quickly activate the resources and capabilities prepared by the preparedness and anticipation capability to resist and limit the impact of unavoidable disruptions (Kamalahmadi and Parast, 2016). The recovery capability makes it possible for the supply chain to be quickly restored to settle into a new state of equilibrium (Colicchia *et al.*, 2010; Rice and Caniato, 2003; Voss *et al.*, 2009; Williams *et al.*, 2009). This is a reactive capability that allows for a return to "normal" operations. Here, the resilient supply chain is able to recruit and integrate the needed resources to overcome the adverse effects of the disruption and resume its pre-disaster state (Zavala-Alcívar *et al.*, 2020). These two resilience capabilities represent the response phase of a supply chain's resilience capability. They align with the second and part of the third capacities of dynamic capabilities as depicted in Figure 1. This is because there's the need to seize opportunities or respond to threats by making sure decisions are timely and market-focused (Barreto, 2010), and that an organisation can maintain competitiveness by enhancing, combining and protecting its resources (Teece, 2007). Irrespective of the type of response (robustness and/or recovery) that was required to overcome a disruption, the fourth capability of a resilient supply chain, adaptability needs it to be able to learn and grow. It does this by first recovering to a better state than before the disruption and by analysing the disruption, the causes and impacts and by developing its capabilities to avoid or better prepare and/or respond to a new occurrence (Ali *et al.*, 2017; Datta, 2017; Stewart *et al.*, 2009; Tatham and Pettit, 2010; Zavala-Alcívar *et al.*, 2020). The intelligence gained from the learning is used through knowledge management and disruptive environment awareness (Zavala-Alcívar *et al.*, 2020) to create a resilience-seeking culture that then feeds into its preparedness capability (Sawyer and Harrison, 2020). This agrees with the reconfiguring aspect of the third DC capacity to transform as presented by Teece (2007).

Insert Figure 1

It is worth pointing out a minor difference between DCV and SCR. Teece *et al.*'s (1997) definition of DC focuses on the firm's ability to address issues in its changing environments. Thus, it seeks to address threats external to the organisation. On the other hand, SCR not only looks at external threats but those within the supply chain and the focus firm as well. Nevertheless, as this study looks at the management of physical resources (in this case, PPEs) in response to the disruptions caused by the COVID19 pandemic, the DC view is appropriate for discussing the resilience of healthcare supply chains. In the wake of the most recent disruption of global scale: the COVID19 pandemic, healthcare supply chains, like all others, suffered varying types of impacts. The resilience capabilities of healthcare supply chains are therefore discussed by analysing how PPEs as resources were leveraged to expedite SCR. This is because resources are a base for developing capabilities (Modgil *et al.*, 2021) and the value of resources are contingent on exogenous factors as shown in the ability to take advantage of opportunities and to neutralise threats in a firm's environment (Mwangola, 2018).

From a DC perspective, resource value is contingent on the changing needs of the customer in the supply chain (de Moura and Saroli, 2021; Teece, 2007). When looking at the delivery and use of PPEs, healthcare professionals are the customers of healthcare supply chains. This research therefore engaged these persons to understand how the supply chains' resilience capabilities were exploited during the global pandemic to avoid and/or respond to its adverse effects on PPE supply and the impact on their well-being.

3. Research Methodology

3.1 Research Framework

This study seeks to offer a unique insight into resilience in healthcare supply chains, particularly as shown in how medical institutions and supply chains responded to the spike in demand for PPEs as a result of the COVID19 pandemic in the UK. An idiographic methodology built on constructionism-interpretivism was judged most suitable due to the exploratory nature of the study (Harrison *et al.*, 2016, 2018; Ponterotto, 2005).

Similar to Mollenkopf *et al.* (2021), this research uses the health and safety of the customer of the supply chain as a desirable well-being outcome. Thus, using the UK's NHS as a single case study, it focuses on the customers' perspective of the impact of the resilience of their healthcare supply chains on their well-being and the actions taken by them and their hospitals to balance mitigation of risk exposure and the careful management of the limited PPE supply. The resilience capabilities identified in SCR literature and the PPEs prescribed by the WHO (2014) to respond to pandemics like COVID19 were used to collect data. This helped to explore how medical institutions prepared for the hikes in demand, the changes that were made in the quantities and quality of the relevant PPEs and how this affected customer well-being. The data was then analysed through the lens of dynamic capability theory as it applies to resilience and the impact this had on the customers of the supply chains was discussed from a transformative research viewpoint.

Case studies are utilised for theory building, theory testing or theory elaboration (Aastrup and Halldórsson, 2008; Ketokivi and Choi, 2014). The study seeks to elaborate on theory. As with humanitarian supply chains, supply chain disruptions in healthcare supply chains have significant implications on human suffering and lives. By taking the customers' experience of the implications of the level of resilience in their hospital's supply chains, the research searches for unique data and creates novel perspectives about SCR, but more specifically the resilience of healthcare supply chains during a pandemic from a transformative supply chain research view. A robust abductive qualitative approach was adopted for this study.

3.2 Method and Data Collection

Qualitative interviewing was employed as the primary means of collecting data. Such an approach is ideal when the aim is to examine people's experience through their social construction of knowledge regarding the selected issue or their points of view (Eriksson and Kovalainen, 2011). This method is the most conducive in understanding “...uncountable, process data peculiar to individuals” (Galloway and Kelly, 2009, p. 8). When complex issues are to be covered, an interview is the best or only means of collecting

data (Saunders *et al.*, 2012). Since resilience is a complex phenomenon, interviews were chosen to provide detailed insights on the impact of this phenomenon on the medical supply chain during the pandemic.

Healthcare professionals are often keen to share their experiences and enjoy telling their stories (Lotz *et al.*, 2015; Zwaanswijk *et al.*, 2011); hence, the use of interviews, which provides this opportunity, can be an effective approach to capture rich data. To enhance consistency and reliability during the process, all interviews were conducted via an interview guide/matrix (King *et al.*, 2019; Yin, 2009). Taking such an approach is useful in ensuring that patterns that emerge in the data can be analysed and studied (Harrison *et al.*, 2018). It was built on the comprehensive literature review conducted, the research aims and the findings of previous studies (Ali *et al.*, 2017; Kamalahmadi and Parast, 2016; Sawyerr and Harrison, 2020).

The interview guide was focused on how provisions were made for gloves (including latex, nitrile, neoprene), fluid repellent surgical masks, filtering face piece (FFP3) respirators, eye protection (both disposable and reusable visors, goggles), disposable plastic apron, and long-sleeved fluid repellent gowns. Questions explored the demand for the PPEs before the pandemic, demand immediately after the pandemic hit, immediate stopgap response to demand hikes and then the organisation's full response. While conducting the interviews, it was ensured that the language employed was comprehensible and clear and the order of the questions asked was logical. In addition, the guide was modified based on insights attained during prior interviews, thus improving subsequent ones. To ensure that bias was not introduced during the interviews, no leading questions were asked. Due to the sensitive nature of the topic, the participants were informed that they were not compelled to provide answers to all questions and reassured of their confidentiality.

3.3 Sampling

In this study, healthcare professionals consisting of doctors, nurses, pharmacists, and a medical device manager were the primary respondents for data collection. A purposive sampling strategy was adopted for the selection of respondents as this approach ensures the selection of cases rich in information about the substantive research problem (Marshall, 1996; Shaw, 1999). The respondents selected for the study

had to be healthcare professionals working with the NHS and must have worked before and during the pandemic. Such knowledge is required to compare the demand of the PPEs before and during the pandemic. 40 respondents were approached but due to the busy schedule of the healthcare professionals during the pandemic, it was impractical to get all of these persons. In total, 22 healthcare professionals agreed to participate in the study. These 22 respondents cut across Scotland and England. Table I provides the details of the healthcare professionals that took part in the study. All respondents are given a pseudonym as shown in the table to ensure anonymity. This was done to make sure that the guidelines on ethics for the study are met.

The interview guide in form of a matrix was initially given to the respondents to complete after which an interview was conducted based on the responses provided in the matrix. The interviews were done virtually via Zoom. The adopted technique proved to be an invaluable tool as suggested by Matthews and Cramer (2008) who are front runners in the use of personal webcams for research. Also, studies by Omeihe *et al.* (2020) and Pretto and Pocknee (2008) affirm the efficacy of the use of virtual platforms which facilitate in-person interviewing as was employed in this study.

Insert Table I

The notion of data saturation was employed to ensure the authenticity of data from the sample (Bryman, 2015). Interviews would be conducted until no new insights are obtained (Harrison *et al.*, 2018). Following the 14th interview, it was deemed that data saturation had been attained. Nevertheless, since interviews had previously been arranged, we conducted eight further interviews with the chosen participants. This allowed for data richness and ensured comparison of data across the groups and individual interviews (Harrison *et al.*, 2018). With the approval of each participant, interviews which lasted about an average of 60 minutes were recorded. The recorded interviews were then transcribed verbatim. The interviewees were informed that their identities would neither be revealed nor be capable of being deduced in potential publications of research findings.

3.4 Data Analysis

The interpretation of data is the core of empirical procedure in qualitative research (Flick, 2011). Data analysis should involve gathering open-ended data, built on posing general questions and creating an analysis from the information provided by the respondents (Creswell, 2009). There are many different methods used by qualitative researchers in analysing data (Bryman and Bell, 2011; Gray, 2009; Saunders *et al.*, 2012). However, since this study is exploratory and its focus is to generate a rich and detailed account of the resilience of the medical supply chain during the pandemic, a type of analysis that helps develop themes from a set of data was required. Based on these pre-suppositions and the utilisation of qualitative interviews as the means of collecting data, thematic analysis as prescribed by King *et al.* (2019) was therefore chosen. An abductive approach was adopted whereby the descriptive and interpretive codes were inductively derived while the overarching themes were imposed from literature from the resilience capabilities. Descriptive codes were also coded under the different PPEs to allow for the distinctive resilience approaches adopted for each PPE to be evaluated. Iterative engagement between the data and the theoretical framework for the research (see Figure 1) facilitated the coding of the actions of participants and their hospitals under the various themes.

The QSR-NVivo 12Pro software package was used in coding and analysing the transcripts. Moreover, in presenting the findings, interview quotes were employed to give voice to the text (Ryan and Bernard, 2003). This method of data analysis was used for the group of interviewees. To make sure that the findings are authentic, they were compared with literature and that themes were consistent across multiple respondents.

4. Findings and Analysis

Findings from the data collected are presented here under the resilience capabilities as presented in the research framework. The PPEs investigated were classified under eye protection, gloves, gowns and aprons, and masks and respirators.

4.1 Preparedness

The first case of the virus in the UK was confirmed on 31st January 2020 (Lillie *et al.*, 2020) and by 31st March 2020, this number had increased to 4,515 (CSSE, 2020). Considering that the World Health Organisation (WHO) had already provided guidelines for infection control of pandemics (WHO, 2014) and the disease had already been declared a pandemic by March 11 (WHO, 2020b), there was enough time to procure extra PPEs in anticipation for a spike in demand for them. For gloves, many of the interviewees affirmed availability. Int_3, a medical doctor indicated: *“Well, I think the supply chain for gloves was stable... So, there have never been a shortage of hand gloves at all. And so, I can say that it was adequate right from before the pandemic and during the pandemic up until this moment.”*

Surgical masks and aprons were moderately available while FFP3 respirators, gowns, visors and goggles suffered widespread unavailability. Besides interviewees 15, 16, 21 and 22, all other interviewees highlighted the unavailability of at least one of the required PPEs besides gloves. Overall, preparation in the UK's healthcare supply chain for a major disruption like COVID19 with regards to PPE availability was varied depending on the particular equipment but generally abysmal.

As a dynamic capability, a supply chain's preparedness allows it to monitor triggers and make adequate preparations to avoid risks. Our findings show that there was a widespread failure within the NHS to sense and shape the threats and opportunities (Teece, 2007) to better position itself to provision PPE supplies (including gloves) for the health professionals. With the knowledge of WHO provisions on infection Control for pandemics (WHO, 2014), a spike in demand for PPEs should have been anticipated and necessary provisions made in preparation. The apparent preparedness with regards to glove provision compared to the other PPEs can justifiably be attributed to the already high demand for gloves (Kwon *et al.*, 2016; Patel *et al.*, 2017) and hence their ready availability in hospitals. Thus, the increase in demand for gloves compared to the other PPEs was relatively lower, thereby translating into a better response due to the availability of extra stock. Similarly, as surgical masks and aprons were already used in hospitals for exposure-prone procedures, there was moderate availability in the immediate aftermath of the pandemic. In the case of gowns, even though there is consistent demand, safety guidelines for their use expanded the demand from use in high-risk areas where aerosol-generating procedures are being performed to use

in wards for patient interaction. Thus, the existing provisions for these proved woefully inadequate. As the use of FFP3 respirators, visors and googles are less frequent, provision for these was significantly low, thereby providing a more accurate view of the preparedness of the supply chains for the disruptions instigated by the pandemic. The supply chain had thereby failed to meet expected demand hikes and adequately provide for the health and safety of its customers as a well-being outcome.

4.2 Robustness and Recovery

Seeing preparation was poor, the hospitals' ability to seize and maintain (see Figure 1) was heavily compromised. The nature of the seizing capability of the DCV involves taking actions to exploit sensed opportunities or mitigate sensed threats (Teece, 2007). When the pandemic hit, the healthcare supply chains were not capable of an adequate response. Safety stock had not been procured, no proper contingency plans had been put in place and so ensuring robustness became a challenge. Consequently, hospitals needed to find other means of ensuring operations were not brought to a halt due to the minimal availability of PPEs. Findings indicate that a major approach adopted to ensure robustness was an artificial reduction in the huge spike in demand. This increase was not only due to the increase in demand by the existing customers of the supply chain (that is, doctors and nurses), but also new customers such as cleaners and administrative staff who now also needed PPEs. Consequently, demand curbing was done through the revision of guidelines for PPE use by the healthcare professionals while visits to hospitals by patients were limited to emergencies, thereby reducing the incidents that required PPE use. Additionally, the use of available pre-disruption stock was restricted and heavily rationed by procurement departments, while the use of expired PPEs and prolonged use of PPEs beyond recommended health and safety requirements became normalised.

From a resilience perspective, these methods proved "successful" in ensuring operations did not halt. Notwithstanding, from a TSCR viewpoint, the failure to adequately develop the dynamic capabilities for robustness resulted in customer well-being (both healthcare professionals and patients) being undermined. As Int_9 highlights, "*There was a mask I think was meant to expire back in 2016, which was covered up stating it will expire by 2022.*" Another doctor said "*So...we found out that the masks were*

expired and a lot of people didn't want to use the masks...then we got a scientific paper to us saying that the masks even though it's past the expiry date were still functional and could protect us from COVID 19" (Int_19). To reassure themselves of their safety, some needed to resort to personal provisioning. Two interviewed medical doctors said, *"So, in the first two weeks, it wasn't available at all. So even if you wanted it, you had to source it yourself. So, I personally sourced for mine initially. I think I got it off the Internet"* (Int_13); *"In the first two weeks of a pandemic, it was a self-initiative. I bought my own goggles, I just got it on Amazon; it was faster that way,...and that's what I've been using since because I have my own pair of protection"* (Int_20).

Response approaches varied for different PPEs. For eye protection, reuse or extended use of disposable visors and restricted access to or rationing of visors helped manage demand requirements. In a few instances (as was the case for goggles), extra stock from previous purchases was available for use. Nonetheless, some health professionals still resorted to personal purchasing of PPEs to protect themselves. For gloves, existing stock ensured sufficient availability even during the height of the first wave for some facilities. There were however various challenges including oversized gloves which resulted in the need to double-glove. When gloves began to run out, extended use of gloves (sometimes up to 2 days) and restricted access to gloves helped manage demand. To better manage spiking demand, Infection Control was not insistent on WHO guidelines on gloves' usage. Standard practice requires gloves to be changed in-between patients under such conditions, but this was not upheld. Similar practices were adopted for the fluid-repellent gowns and aprons. In a few instances, the extra stock of previously purchased masks and FFP3 respirators helped maintain service delivery. It must be noted that these provisions were not made in anticipation of disruptions.

For a customer to be convinced during the pandemic that the health supply chain had recovered from the disruptions into a new state of equilibrium, they needed to be assured that their safety was deemed paramount, that adequate PPE provisioning had been made and that the guidelines for their usage aligned with WHO standards for a pandemic. In the case of this pandemic, it was desirable that the supply chain would settle into a state of equilibrium where provision for the significantly higher levels of demand for PPEs that had become the new normal, was guaranteed. Hospitals resorted to using alternative suppliers

and borrowing from other facilities while private companies also intervened by making donations. Int_20 indicates *“I think...they had to purchase from some local companies. I saw the branding of a company in Bristol... There were some people that donated and companies that donated aprons as well”*. As at the period of data collection, the predominant view of interviewees was that adequate provision had been made for visors, gloves, disposable aprons and surgical masks, thereby affirming the recovery of those supply chains.

Guidelines that were modified due to shortages were realigned with WHO provisions. On this, Int_17 explained that *“...the guideline kept changing because it looks like it changed based on or depending on the availability. Initially, we were asked to use it only when we believe that the patient was covid positive and that’s tested positive whether the patient is in theatre or outside of theatre. But that is not what it is now. ...Also now we are expected to use the full PPEs and FFP3 when we are operating on a patient using general anaesthesia.... But previously, it wasn’t like that. You know, when you have somebody who does not have any symptoms and is unlikely to be covid positive, we were not using full PPEs.... That guideline changed quickly, that everybody should use the full PPEs once you are operating on a patient who is undergoing general anaesthesia for any surgical operation...”*. Notwithstanding, the continued shortage of goggles, fluid repellent gowns and FFP3 respirators indicated these supply chains had not fully recovered from the disruptions. Thus, even though the ability to ‘seize’ as a dynamic capability had been abysmal due to poor ‘sensing’, ‘maintaining’ had not (see Figure 1). Per the DCV, the capacity to maintain involves enhancing, combining and protecting both tangible and intangible assets (Teece, 2007). The approach used in these supply chains, however, was demand curbing, resource rationing and overexploitation, and alternative (including personal) supplementary resource provisioning to facilitate coping with the scarce resources. This was how robustness, however fragile, was attained.

4.3 Adaptability

Adaptability aligns with the DCV’s reconfiguring part of the transformation capability. It is in this phase where there is learning from the response of the supply chain to disruptions to develop new capabilities for better preparedness and to exploit these capabilities over competition. At the time of data collection,

the effects of the disruptions caused by the pandemic still lingered and so there was not much evidence for lessons learnt. It was not readily obvious that the well-being of healthcare professionals had significantly improved. For example, goggles, gowns and FFP3 respirators were still in short supply several weeks after the start of the pandemic, indicating these supply chains had yet to fully recover and adapt. Some interviewees were still not clear about the protocols on some PPE usage and whether enough provisions for their safety was being made. Int_3 pointed out that:

“So the gown, I think they will need to increase the supply because that gown gives your whole body a covering and I think the only place that is exposed is just your legs and your neck, which is OK... Then the FFP 3 mask also needs to be fully available also, and they need to be very clear on their protocols, you know, like when to use these and when not to use them”.

Notwithstanding, gloves had been largely provided across the country with provisions made accessible in hospital wards. As Int_17 explains *“So they placed more gloves in those rooms. You were not expected to wear gloves into every room. So, it wasn’t obvious that we had more gloves because more gloves were only placed on those trays where we were expected to nurse covid patients.”* The global supply chain for the provision of gloves proved the most adaptable (Dallas *et al.*, 2021) even though concerns about forced labour have been raised (Hughes *et al.*, 2022). Regardless, as the health and safety of healthcare professionals require full PPE provision per WHO guidelines, the success in glove provision and some of the other PPEs did not contribute overwhelmingly to assure customers of improved well-being. Trust had been broken and full provision was still not made several months into the pandemic. Table II and Table A1 in the Appendix provide further insight into the study’s findings.

To satisfactorily assure the well-being of its customers, the healthcare supply chains responsible for the provision of essential pandemic-requisite PPEs have to fully recover and adapt. New dynamic capabilities have to be developed and relevant resources across the supply chain have to be combined and reconfigured to assure the health and safety of hospital personnel. The next section makes recommendations towards this end.

Insert Table II

5. Developing Dynamic Capabilities to Facilitate Healthcare Supply Chain

Adaptability for Customer Well-being

Our findings have shown that the well-being of the customers of healthcare supply chains was severely compromised due to the vulnerability of these supply chains to the disruptions caused by the COVID19 pandemic. Central to the management of supply chains is the delivery of value to the customer (Christopher, 2011). When supply chains are not resilient enough to withstand disruptions, not only is the value proposition to customers severely imperilled, but in the case of healthcare supply chains, their very lives may be in danger. Findings from this research provide a good basis to instigate learning from the disruptions and reconfiguring resources and capabilities in healthcare supply chains to adapt and be in a better position than before the COVID disruptions. We, therefore, make recommendations to improve on the dynamic capabilities to sense and shape (R1) and to seize and maintain (R2) (See Figure 2). Incorporating these will facilitate the reconfiguration needed to improve adaptability.

To sense threats, an organisation has to be able to scan, create, learn and interpret. This requires investment in developing the resources and capabilities to probe and reprobe not only potential external threats but also both expressed and latent customer needs (Teece, 2007). The findings of this research show that this capability is severely lacking in the NHS supply chains. Despite prevailing evidence in the early stages of the pandemic of the potential of disruptions of its supply chains in Asia – where it sources most of its gloves (Hughes *et al.*, 2022), our results show the NHS did not make the needed changes to address the relative minimal hike in demand for gloves which was already high pre-pandemic. The severe shortage in gowns, googles and FFP3 respirators further emphasise the failure to sense and shape.

Seeking operational efficiency (by exploiting economies of scale, better negotiation prowess and the removal of duplicating overlapping contracts), much of the NHS' procurement is centralised and done through the NHS Supply Chain's Supply Chain Coordination Limited (SCCL). The need to invest in improving the sensing capability of this management body cannot be overstated. Improved visibility and understanding of its supply chains to facilitate situational awareness are requisite. Mapping of existing supply chains to drive better coordination and knowledge sharing, and to identify areas of vulnerability

can help in this regard. Investing in Information Technology (IT) infrastructure (Brandon-Jones *et al.*, 2014; Jüttner and Maklan, 2011) to enhance visibility beyond first-tier suppliers and instituting early warning strategies (Sáenz and Revilla, 2014) and continuity planning (Pettit *et al.*, 2010) will improve on its sensing and shaping capability. Blockchain technology may prove useful in implementing this (Golan *et al.*, 2020; Orcutt, 2020).

Increasing cooperation and information sharing should not only be vertically (among supply chain entities) but horizontally (between healthcare facilities) and internally (between wards, departments and functions within hospitals) as well. The SCCL should have competent supply risk management teams that monitor potential sources of disruptions and develop contingency plans accordingly (Emmett, 2019). Additionally, understanding the WHO's requirements for pandemics could have helped the procurement team to better forecast the demand spike and the implications on the well-being of healthcare professionals (and patients). Training of procuring officers to incorporate customer well-being (particularly, health and safety) in addition to economic expediency and operational efficiency considerations in their decision making will improve their ability to make commensurate preparations required to avoid, contain or control risks (Ali *et al.*, 2017; Sheffi, 2001).

Insert Figure 2

There is also the need to develop the capability of healthcare supply chains to 'seize' and 'maintain' (see Figure 2) using proven supply chain techniques that incorporate customer well-being. For resilience, this would require them to be robust and agile. To do this, proactive management is of utmost importance. The visibility and understanding gained from mapping the supply chains will allow for strategic decisions on the design of the supply chains to be made to attain robustness and agility (Klibi *et al.*, 2010). For the supply of PPEs, a strategic approach to composing and managing the supplier base is critical. Sourcing flexibility may be pursued through the use of flexible supplier contracts (such as framework agreements, quantity flexible contracts and option contracts) (Datta, 2017; Nikkhoo *et al.*, 2018; Pettit *et al.*, 2010, 2013; Tang, 2006; Tukamuhabwa *et al.*, 2015), backup suppliers (Aldrighetti *et al.*, 2019; Hohenstein *et al.*, 2015), multiple sourcing including the use of transportation (modes/routes), location (local/overseas) and service/product mix (Jüttner *et al.*, 2003; Pereira *et al.*, 2014; Tukamuhabwa *et al.*, 2015; VanVactor,

2011), and supplier selection which carefully considers a supplier's capability to respond to variations in supply requirements (Manders *et al.*, 2017). Humanitarian organisations are experts in dealing with demand surges (Oloruntoba and Gray, 2006; Oloruntoba and Kovács, 2015). Strategic use of framework agreements – as used by humanitarian organisations, can help mitigate supply risks to ensure there is enough PPE provision to not compromise employee well-being. The use of safety stock may be important at each facility, but a better strategy may be through the use of pooled inventory within NHS trusts so that hospitals will not have to keep excess buffer (Burns *et al.*, 2015; Zepeda *et al.*, 2016). This research shows that the trust of the healthcare professionals in management to seek their well-being was broken due to some of the means adopted to ensure robustness. Even though most of the approaches the health workers could use were regulated by the NHS' Infection Control, the findings also indicate that healthcare personnel circumvented the NHS' pre-existing supply chains and procurement functions to secure their well-being and that of their patients. Regardless that this contributed to the robustness of their hospitals' response to the disruptions, it was detrimental to the overall resilience of the central NHS supply chain, seeing that its customers had lost trust in it. Instituting a resilience-seeking culture (Sawyer and Harrison, 2020), which not only ensures the early sensing and mitigation of PPE supply disruptions but also reassures healthcare supply chain customers of their well-being is recommended. Joint problem-solving and transparency can be useful to build this trust. As an interviewee indicated, if staff were given assurance of the continued reliability of expired surgical masks without attempts to redate them, there would have been less resistance to their use.

6. Implications

As more and more disruptions have shown that the implementation of conventional supply chain management optimisation techniques has made supply chains more vulnerable, the interest in ensuring supply chains are resilient both in research and practice has increased. The COVID19 pandemic accentuated this. For healthcare supply chains, the added component of the risk to human lives in the event of disruption further heighten the non-negotiability of their resilience. However, unlike VanVactor (2011), Bradaschia and Pereira (2016), Mandal (2017), Rubbio *et al.* (2019) and similar others that

explored resilience in healthcare supply chains, this research has focused on resilience from the supply chain customers' perspective. By adopting a transformative supply chain research approach to resilience, we have shown the impact of healthcare supply chain vulnerability to the COVID19 pandemic, not only on critical materials (PPEs) provision, but even more importantly, on the well-being of its customers – healthcare professionals. We have therefore introduced an interesting dimension of supply chain resilience studies that focuses on customer well-being. Like Eltantawy (2016), Chowdhury and Quaddus (2017), Mwangola (2018) and Hendry *et al.* (2019), we have shown the usefulness of DCV in analysing SCR. In our case however, we have used the theory to make recommendations on how healthcare supply chains can reconfigure their resources and capabilities to adapt to a better state than they were before the COVID19 disruptions; a state where resilience also ensures customer well-being. By combining DCV with TSCR to analyse supply chain resilience, we have introduced the well-being of individuals (customers and employees) into supply chain resilience research.

From a practical standpoint, we first bring the attention of procurement and supply chain managers to the effect of their decisions on the well-being of their customers. We have highlighted how the lack of trust in the ability of their official supply chains to provide them safety resulted in them seeking support from alternative sources. Furthermore, having pointed out the failures in preparedness and the response of their supply chains, recommendations on how to exploit their adaptive capacity to minimise their supply chain vulnerabilities and improve resilience have been provided.

As we have shown how Infection Control's directives proved detrimental to customer well-being, to the point where they were deemed untrustworthy enough for them to seek out their own forms of protection, there is the need for new policy directives that ensure that the well-being of health professionals is not compromised – especially by giving directives that are contrary WHO guidelines. It is important that going forward, prescriptions for robustness and recovery exploit proven supply chain resilience techniques rather than the use of expired stock and artificial manipulation of demand.

7. Future Directions and Conclusion

This research needs to be looked at along with some limitations. Our decision to look at resilience from a customer's perspective gave us unique insights as to the impact of disruptions on vulnerable healthcare supply chains on customer well-being. As these professionals were the ones 'on the ground', the insights they provided represent the real impact of the vulnerability of the supply chains studied, as opposed to the procurement professionals who are detached from the direct implications of the supply chain vulnerabilities during the crisis. This however meant that we were not going to be able to ascertain the actual reasons for the failure to adequately prepare for the disruptions. Additionally, being at the receiving end of the impact of the disruption, it is acknowledged that the persons interviewed could be biased, but this was mitigated through triangulation within the data as well as with literature. Notwithstanding, interviewing supply chain and procurement professionals within the healthcare supply chain would have helped provide some understanding of the actions taken to mitigate some of the risks experienced and the reason why after several weeks, multiple PPEs were still short in supply. Poor supply chain resilience practices, from a human resource management perspective, could be from inexperienced or incompetent staff and/or the absence of the right levels of power and enabling to take and enact decisions. Engaging these professionals would have helped explore these in healthcare supply chains in the UK.

These however provide opportunities for future studies. Interviewing logistics, supply chain and procurement professionals in the healthcare industry will be useful as it will open up the challenges within the sector a lot more for further research and solution propositions. As qualitative research provides rich and detailed data on the state of healthcare supply chains, decision models to inform supply chain design, supplier selection and equipment delivery to enhance supply chain resilience could be beneficial. Finally, our focus on customer well-being opens up research opportunities into the impact of supply chain vulnerabilities on customers in commercial, pharmaceutical, and humanitarian supply chains. Incorporating customer well-being into supply chain resilience research and practice is well overdue.

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TABLES

Table I Details of healthcare professionals who participated in the research

Interviewee	Occupation	Ward	Location
Int_1	Medical doctor	IAU, Respiratory ward and Geriatric	Glasgow and Clyde
Int_2	Medical doctor	Acute medical admissions, Covid19 wards and Geriatric wards	Nottingham
Int_3	Medical doctor	General Medical wards and HDU	Melrose
Int_4	Nurse	Paediatrics (General Medical ward)	Central London
Int_5	Medical doctor	Acute Receiving Unit, Gastroenterology	Glasgow and Clyde
Int_6	Nurse	Coronary Care	Sheffield
Int_7	Medical doctor	Primary Care	North East of England
Int_8	Pharmacist	Pharmacy	East London
Int_9	Medical doctor	Old Age Psychiatry	Glasgow and Clyde
Int_10	Pharmacist	Pharmacy	West and East Hertfordshire and Essex
Int_11	Student Nurse	Community	South Lanarkshire
Int_12	Nurse	ICU	London
Int_13	Medical doctor	Primary Care	Coventry
Int_14	Medical doctor	ICU/Acute Medicine	Essex
Int_15	Medical Device Manager	Medical Physics	Lanarkshire
Int_16	Medical Doctor	Trauma/Accident and Emergency	Harrow, Greater London
Int_17	Medical Doctor	Gynaecology	Southampton and Carlisle
Int_18	Medical Doctor	Accident and Emergency	Essex, Harlow
Int_19	Medical Doctor	Out of Hours	Glasgow and Clyde
Int_20	Medical Doctor	Obstetrics and Gynaecology	King's Lynn
Int_21	Medical Doctor	Out of Hours	Glasgow and Clyde
Int_22	Nurse	Community	Hertfordshire

Table II. Summary of resilience capabilities for PPEs

PPEs	Resilience capabilities			
	Preparedness	Robustness	Recovery	Adaptability
Eye protection	Widespread unavailability of eye protection (visors, goggles) at the start of the pandemic Limited goggles and visors in stock	Extended use of visors and goggles or reuse of disposable visors Personal procurement of visors and goggles by medical staff Existing stock ensuring sufficient availability of goggles Restricted access to or rationing of visors	Adequate provision of visors and/or goggles to meet prevailing demand Continued lack of goggles	No lessons learnt in some trusts with respect to the provision of goggles as they are still unavailable
Gloves	Widespread provision due to already high usage rates	Existent provision ensured sufficient availability of gloves Extended use of gloves, using at most 2 a day Double-gloving to be able to use oversized gloves Redefinition of guidelines, protocols and procedures by Infection Control on the use of gloves Restricted access to or rationing of gloves	Adequate provision of gloves even to the extent of allowing for double gloving Revision of initially provided guidelines for gloves usage to align with the provision in WHO standard requirements	Provision of gloves at the doors of every ward

Gowns and aprons	Widespread unavailability of gowns at the beginning of the pandemic Moderate availability of aprons at the start of the pandemic	Extended use of gowns and aprons Pre-planned provision thereby ensuring sufficient availability of gowns Redefinition of guidelines, protocols and procedures by Infection Control on the use of gowns and aprons Restricted access to or rationing of gowns	Use of alternative suppliers Borrowing from other wards or hospitals Donations by individuals and private companies Continual shortage of repellent gowns	Widespread unavailability of gowns implies no lessons learnt yet
Masks and respirators	Moderate availability of surgical masks Widespread unavailability of FFP3 respirators	Use of expired masks Extended use of masks, sometimes saving same masks for a second day Personal procurement of masks by medical staff Existent stock ensured sufficient availability of masks and/or FFP3 respirators Redefinition of guidelines, protocols and procedures by Infection Control on the use of masks and FFP3 masks Restricted access to or rationing of FFP3 respirators	Use of alternative suppliers Adequate provision of surgical masks Continual inadequacy of FFP3 respirators thereby resulting in maintenance of restrictive access and rationing	Widespread availability of surgical masks but unavailability of FFP3 masks indicate no lessons learnt

APPENDIX

Table A1 A summary of the actions reported by interviewees as compared to the WHO guidelines on use of PPEs

PPEs	Gloves (Latex, nitrile, neoprene glove)	Medical masks (Fluid repellent/resistant (type IIR) surgical mask and FFP3 (Filtering face piece) respirator)	Eye protection (visors (disposable, reusable), goggles)	Long sleeved fluid repellent gown and disposable plastic apron
WHO standard summary Source: WHO (2014)	- Put on gloves each time there is contact with body fluids, blood, excretions, secretions, non-intact skin, or mucous membrane is foreseen. - Switch gloves between procedures and tasks on the same patient after interaction with potentially infective substance. - Put on nonsterile, tidy latex gloves, throwing them away after each patient interaction.	- Medical masks must be switched after every use or if they become dirty or wet. - Put on facial protection, including eye protection and medical mask (goggles or face shields), to protect the conjunctivae and the mucous membranes of the eyes, nose and mouth during actions that may cause sprays or splashes of body fluids, blood, excretions, or secretions. - At a bare minimum, it is expected you use a medical mask (procedure or surgical mask) if working less than one metre from the patient. - Utilise a particulate respirator that is at least as protective as the NIOSH-certified N95 or its counterpart when going into the isolation area or room, or when delivering care to a patient with a preferential or obligate airborne infectious disease in other sites. - There are no recommendations at	- Use eye protection, because sprays of secretions may happen, when delivering care in close interaction with a patient that has respiratory symptoms (e.g. sneezing or coughing), - Reusable eye protective equipment can be utilised (e.g. face shield or goggles), but may cause a possibility of cross-infection if not decontaminated and cleaned appropriately based on the manufacturer's instructions after every use. - Conventional eye glasses should not be used as eye protection, because they are not devised to guard against sprays to the mucosa of the eye.	- So far, the gown does not come into direct interaction with any patient, they may also be worn while delivering care to more than one patient in a single cohort area only. - Put on gowns to safeguard the skin and avert staining of clothing during actions that are prone to produce splashes or sprays of body fluids, blood, excretions or secretions. - Choose a gown that is suitable for the action and the quantity of fluid expected to be faced. Put on a waterproof apron over the gown if spraying or splashing of potentially infectious material is projected and the gown in use is not fluid resistant. - A stained gown should be removed as quickly as possible. - A washable cloth gown or a disposable gown made of synthetic fibre should be used; make sure that it is the right size to completely cover the areas to be protected. - Put on a gown once only if possible. - Put on an apron to lessen penetration of fluid (do not use an apron only to avert contact contamination), if the gown is

		this time, on the reuse of respirators when treating patients with ARIs, and respirators and medical masks should be thrown away after each use in these cases.		permeable. • If quantities of gowns for health-care workers are constrained, focus on the use of gowns for aerosol-generating actions that have been constantly linked with a heightened risk of pathogen transmission and for actions that involve close interaction with the patient.
Int_1	Immediate response phase: Use of double gloves Recovery phase: Use of double gloves	Immediate response phase: Surgical masks were initially not available, but provision was made at the entrance of wards and in wards. Use of FFP3 respirators was not required. Recovery phase: Increased availability of surgical masks across hospital. Occasional availability of FFP3 respirators in CCU/ITU/IAU CPR Procedure.	Immediate response phase: Eye protection (visors and goggles) were not immediately available. Reusable visors were initially made available when working on COVID positive patients and in AMU, A/E, ICU and CCU. Recovery phase: Increased availability in A/E and CCU.	Immediate response phase: Long sleeved fluid repellent gowns were not available in the early response phase of the pandemic. Recovery phase: Occasional provision is made in CCU/ITU/IAU CPR Procedure
Int_2	Immediate response phase: Use of gloves to see all suspected COVID19 patients Recovery phase: Use of gloves when examining all patients	Immediate response phase: Fluid repellent masks to be used when examining all suspected COVID19 patients Recovery phase: Masks are worn by all staff in clinical areas.	Immediate response phase: FFP3 respirators used for aerosol producing procedures and eye protection used in invasive procedures Recovery phase: Trust (dubiously) redefined aerosol generating procedures. Eye protection was required for	Immediate response phase: Worn when seeing all COVID19 positive patients along with disposable plastic aprons. Recovery phase: Long-sleeved fluid repellent gowns to be worn only in aerosol generating procedures, with aprons worn when attending to all patients in clinical setting.

			both invasive and non-invasive procedures.	
Int_3	Immediate response phase: Gloves used on all patients Recovery phase: Gloves used on all patients	Immediate response phase: Surgical masks made available. No FFP3 respirators were used. Recovery phase: Enough surgical masks were available and FFP3 respirators were reserved for aerosol generating procedures.	Immediate response phase: Limited availability of visors resulting in reuse of disposable visors after cleaning and disinfection. Availability of goggles were limited as well. Recovery phase: Increased availability of disposable visors.	Immediate response phase: Gowns were not available at all. Aprons however were available for use. Recovery phase: Fluid repellent gowns were only available in special wards.
Int_4	Immediate response phase: High turnover for gloves. Even though gloves were available, appropriate sizes weren't available and so improvisations had to be made. Recovery phase: Increased availability of gloves for use.	Immediate response phase: Initial indication was for FFP3 respirators to be used at all times. With this becoming impractical, they were left for special procedures while surgical masks were to be used for all other situations. Recovery phase: Increased availability of FFP3 respirators.	Immediate response phase: Goggles and reusable visors were available, with visors being preferred for aerosol generating areas. Recovery phase: Eye protection equipment were available.	Immediate response phase: Gowns were available for use. Extra disposable plastic aprons were used in-between patients. Recovery phase: Continued availability of gowns and aprons.

Int_5	Immediate response phase: Gloves were readily available for use when examining all patients. Recovery phase: Gloves usage has reduced due to our ability to confirm COVID-19 cases so that usage now is as the situation demands.	Immediate response phase: Surgical masks were available for us. Use of FFP3 respirators were reserved for use in emergency cardiac arrest situations. Recovery phase: Declined usage with reducing numbers of COVID-19 admissions. Use of FFP3 respirators remained as in the immediate response phase.	Immediate response phase: No eye protection equipment immediately available. However, reusable visors were subsequently made available. Recovery phase: Availability of disposable visors for use.	Immediate response phase: Gowns were not readily available for use except for cardiac arrest calls. However, aprons were required when entering every room. Recovery phase: Aprons were only used for COVID-19 patients as indicated by infection control while gowns were used for cardiac arrest calls for COVID-19 patients.
Int_6	Immediate response phase: Nitrile gloves were readily available when needed. Restocking was done once quantities ran low. Recovery phase: Continued availability.	Immediate response phase: Increased use of masks. FFP3 respirators were required when dealing with COVID-19 patients. Recovery phase: Continued use as in the immediate response phase.	Immediate response phase: Disposable visors had to be reused multiple times because stock was low. Recovery phase: Increased availability of visors.	Immediate response phase: Aprons were available for use on all patients but ran out quickly and some additional ones had to be borrowed from other wards until stock was replenished. Gowns were only to be used on COVID-19 patients. Recovery phase: Continued usage of aprons and gowns as before.
Int_7	Immediate response phase: Use of nitrile gloves for all patients. Recovery phase: Continued use of nitrile gloves on all patients.	Immediate response phase: Started using masks for all patients. No use of FFP3 respirators at all. Recovery phase: Same as in the immediate response phase.	Immediate response phase: Disposable visors had to be reused for patients with coughing or COVID-19 patients due to unavailability. Recovery phase: Use of reusable visors.	Immediate response phase: Use of plastic aprons for all patients. No use of long-sleeved repellent gowns. Recovery phase: Continued use of plastic aprons for all patients.

Int_8	Immediate response phase: Increased use of gloves for the whole team. Recovery phase: Every team has gloves available to change how often as they like; usually twice a day.	Immediate response phase: Unavailability of masks in the immediate aftermath. Provisions were subsequently made after staff were required to use reusable visors. Recovery phase: Masks now available for use. No FFP3 respirators have been used.	Immediate response phase: No visors were immediately available. Recovery phase: Visors now available. Team members have the option of using the visors or the masks.	Immediate response phase: N/A Recovery phase: N/A
Int_9	Immediate response phase: Switching gloves after every patient Recovery phase: Maintaining the switching of gloves after every patient	Immediate response phase: Surgical masks were available but there were issues with quality. Expired masks were being used. Masks that had expired in 2016 were covered with a tag of 2022. Switching to the use of different masks for patients. FFP 3 respirators not available Recovery phase: Use of masks for every session which depends on the ward. A session is about 3 to 4 hours in the ward. FFP 3 respirator now available but used for special cases (i.e. resuscitation)	Immediate response phase: Reusable visors and goggles were not immediately available. Disposable visors were available and were being reused rather than disposed after use. Disposable visors were shared one per day and wiped for the next person to use Recovery phase: Availability of all visors (i.e. Disposable and Reusable) and goggles	Immediate response phase: Plastic aprons were readily available for use. However, gowns were not available and were deemed not necessary Recovery phase: Continued availability of aprons

Int_10	Immediate response phase: All staff wore latex or nitrile gloves as part of PPE. Unavailable for a short period and staff had to keep the same gloves on and change it maximum twice in a day. Recovery phase: All staff wear gloves. Gloves are changed twice in the morning and twice in the afternoon.	Immediate response phase: Staff wearing masks in pharmacy and dispensary. FFP 3 respirators not available and not used Recovery phase: Some staff wear masks but not everybody. FFP 3 respirators not available and not used	Immediate response phase: No visors and goggles were immediately available Recovery phase: Visors are now available. Staff serving patients on tills and doors wear reusable visors	Immediate response phase: Aprons were readily available. Staff wear apron as part of PPE. Gowns not available Recovery phase: Continuous availability of aprons. Some staff wear aprons. Gowns not available.
Int_11	Immediate response phase: Shortage of gloves initially. Double gloving themselves and using more gloves per patient if needed Recovery phase: Gloves are now more readily available. More gloves are being used.	Immediate response phase: Shortage of surgical masks initially. Limited availability and surgical masks only used when the patients had the symptoms. FFP 3 respirators not available Recovery phase: Surgical masks are now readily available. Limited availability of FFP 3 respirators and only used when the patient has been confirmed with COVID-19.	Immediate response phase: No visors and goggles were immediately available Recovery phase: Limited availability of visors and goggles and use dependent on the confirmed case of COVID-19	Immediate response phase: Aprons were available, used one per patient and disposed when soiled. Gowns were not immediately available Recovery phase: More aprons being used as required. Gowns were still not readily available

Int_12	Immediate response phase: Limited availability gloves- told to only use gloves when carrying out 'dirty' procedures otherwise wash or sanitise your hands. Ran out of sterile surgical gloves. Initial use was zero but rose to 3. Had to double glove for the nitrile gloves and there were size mismatches Recovery phase: Gloves are now more readily available. More gloves are being used	Immediate response phase: Surgical masks were available, and requirements met. FFP 3 only used for 12 hours (i.e. 2 breaks in a shift) and some variations were not readily available e.g. FFP 3 with filters Recovery phase: Surgical masks available and worn in all places. All types of FFP 3 now available	Immediate response phase: Initially required to reuse the disposable visors. Goggles is a part of the full PPE and used interchangeably with visors depending on the availability Recovery phase: Roughly two weeks to address the stock challenges but the visors and goggles are now readily available	Immediate response phase: They wiped aprons in between not tie new ones around neck. Basically, due to safety and not stock issues they were using the same gowns per bay and wipe in between patients. Repellent gowns i.e. theatre gowns ran out of stock and had to wear plastic aprons in their place. This happened for less than a week Recovery phase: Gowns and aprons are now readily available.
Int_13	Immediate response phase: Gloves were readily available and worn for every patient contact Recovery phase: Continuous availability of gloves and worn for every patient contact	Immediate response phase: There was limited availability initially for surgical masks. Surgical masks worn for all patient contact. FFP 3 respirators not available and not used Recovery phase: Surgical masks are now readily available. Surgical masks now worn for all patient and staff contact. FFP 3 respirators not available and not used.	Immediate response phase: Visors and Goggles were not available. Self-sourcing of own visor initially Recovery phase: Re-usable visors now used for every patient contact provided by the practice. Disposable visors and goggles are not available	Immediate response phase: Aprons were available but by chance because the nurses used them. Aprons worn for every patient contact. Practice sourced gowns for doctors but not recommended by the public health guide for primary care Recovery phase: Continuous availability of aprons and worn for every patient contact. Gowns worn during home visit to patients

Int_14	Immediate response phase: Increase in the availability of gloves of all sizes. Gloves used per patient Recovery phase: Continuous availability of gloves and worn for every patient contact	Immediate response phase: Surgical masks have become much more available and widespread within the hospital. With mask stations at the entrance of each ward and accident and emergency. Shortage of a variety of FFP 3 respirators but quick to respond in providing other substitute FFP 3 masks Recovery phase: Continuous availability of surgical masks. Masks to be worn before you enter the ward and outside the patient bay. Large increase in stocked FFP 3 respirators.	Immediate response phase: Goggles were widely available and a large increase in the use of goggles initially Recovery phase: As the pandemic progressed goggle usage was replaced by use of visors exclusively because they were apparently not effective. Visors are readily available	Immediate response phase: Gowns and aprons were available. Aprons were rarely used except in wards with no confirmed cases. Gowns were used because they were deemed safer. Recovery phase: An attempt to reuse gowns by washing them didn't work as the gowns fell apart. Continuous availability of gowns.
Int_15	Immediate response phase: Gloves were readily available. Removal before leaving a clinical area and between the use of medical devices Recovery phase: Continuous availability of gloves. Removal before leaving a clinical area and between the use of medical devices	Immediate response phase: Surgical masks not used. Full team fit tested for the FFP 3 and used when entering ICU Recovery phase: Reduced number of personnel entering the wards based on the risk to reduce the need for the FFP 3 respirators	Immediate response phase: Visors and goggles were available and were used when going to the high dependency units and intensive care Recovery phase: Continuous availability of visors and goggles. Limited exposure to those areas (i.e. high dependency units and intensive care). Used based on risk and requirement	Immediate response phase: Plastic aprons were available but not used in COVID positive areas. Long sleeved repellent gowns were available and used in COVID positive areas Recovery phase: Continuous availability of aprons and gowns. Use of gowns in COVID areas

Int_16	Immediate response phase: Gloves were readily available. No significant change in the use of gloves Recovery phase: Continuous availability of gloves. Gloves now required for all patient contact	Immediate response phase: No change in the use of surgical masks due to lack of availability and prioritising its use in operating theatres. FFP 3 were available and used when in direct contact with suspected or confirmed COVID positive patients Recovery phase: Surgical masks are required to be worn at all times and changed with every patient contact. FFP 3 are available to use when in direct contact with confirmed COVID positive patients	Immediate response phase: Visors and goggles are available to use when in direct contact with suspected or confirmed COVID positive patients Recovery phase: Visors and goggles are available to use when in direct contact with COVID positive patients	Immediate response phase: Aprons were readily available. No significant change in the use of aprons. Gowns are available to use when in direct contact with suspected or confirmed COVID positive patients. Recovery phase: Continuous availability of aprons. Aprons now required for all patient contact. Gowns are available to use when in direct contact with confirmed COVID positive patients
Int_17	Immediate response phase: Gloves were readily available. There were no clear guidelines on its use and gloves were used as required. Gloves were just used for examination of patients Recovery phase: More gloves provided and now required when going to see any patient	Immediate response phase: Surgical masks were readily available. No significant change in the use of surgical masks. FFP 3 respirators were available but only used when the patient has COVID symptoms Recovery phase: Guideline changed after two weeks so more surgical masks have been used. Surgical masks are required to be worn at all times and worn to see every patient. FFP 3 are available and used for every patient operation	Immediate response phase: Visors and goggles were readily available. No significant change in the use of visors and goggles. Recovery phase: More visors and goggles provided. Guidelines changed and visors are used for every operation or procedure but not used for random consultation	Immediate response phase: Aprons were readily available. No significant change in the use of aprons. Gowns not available and not required Recovery phase: More aprons provided. Guidelines changed and aprons are used for every operation or procedure but not used for random consultation. Gowns not available and not required.

Int_18	Immediate response phase: Gloves were readily available when examining patients. Gloves were changed after every single surface touched, every procedure and every event. Demand was met Recovery phase: Continuous availability of gloves	Immediate response phase: Surgical masks were readily available, and demand was met. Limited availability of FFP 3 initially. Used only to see COVID patients. It was only given to senior doctors who were admitting. It was being rationed Recovery phase: Took quite some time for provision to be made for FFP 3. More surgical masks were provided but it took a long time	Immediate response phase: Some challenges initially in getting the visors and goggles. Disposable visors were used. They were rationed Recovery phase: Later provision was made for the visors and goggles	Immediate response phase: Plastic aprons were readily available, and demand was met. Plastic aprons were worn for every patient contact. Minor availability issues for the gown. Gowns were worn only in high risk areas. Recovery phase: Continuous availability of aprons. Later provision was made for gowns.
Int_19	Immediate response phase: Gloves were available and used as required. Gloves were worn for every patient consultation. No shortages noticed Recovery phase: Continuous availability of gloves with no shortages	Immediate response phase: During the first two days, a surgical mask was used per patient. The 3rd day, we were told you could use the surgical masks for 4 hours regardless of the number of patients but after the 3rd day, we reverted back to a surgical mask per patient. FFP 3 respirators were not available and not required but some doctors sourced for theirs personally. Recovery phase: Continuous availability of surgical masks and used per patient. FFP 3 not available and not required.	Immediate response phase: Limited availability of eye protection initially. Reusable visors made available one per shift. Disposable visors, eye shields and goggles phased out Recovery phase: More availability of reusable visors. Reusable visors available per staff	Immediate response phase: Aprons were available and used during patient consultation. One apron per patient consultation. Gowns not available Recovery phase: Continuous availability of aprons and used for every patient consultation. Gowns not available and not required

Int_20	Immediate response phase: More nitrile gloves purchased, and gloves were worn for every patient contact Recovery phase: Continuous availability of gloves with no shortages	Immediate response phase: More surgical masks procured. Surgical masks used for every patient contact. FFP 3 rationed to mostly affected areas. Recovery phase: Procurement of more surgical masks and FFP 3. FFP 3 reserved for confirmed COVID cases	Immediate response phase: Visors and goggles were limited in availability. Goggles were self-purchased. No clear guidelines on who was to use eye protection Recovery phase: Eye protection provided but limited in availability. Only used for COVID suspected or confirmed cases	Immediate response phase: Increased supply of plastic aprons. Plastic aprons used for every patient contact. Gowns used for only confirmed or suspected COVID cases Recovery phase: Increased supply and procurement of aprons and gowns.
Int_21	Immediate response phase: Gloves were readily available. Use of latex gloves for every patient seen. All patients seen while donning gloves Recovery phase: Continuous availability of gloves. Use of latex gloves for every patient seen. All patients seen while donning gloves	Immediate response phase: Surgical masks were readily available. Use of surgical masks for every patient seen. All patients seen while donning surgical masks. FFP 3 not available and not required Recovery phase: Continuous availability of surgical masks. Use of surgical masks for every patient seen. All patients seen while donning surgical masks. FFP 3 not available and not required	Immediate response phase: Eye protection using reusable visors were used for all patients, cleaned after seeing each patient Recovery phase: Continuous availability of eye protection. Eye protection using reusable visors were used for all patients, cleaned after seeing each patient	Immediate response phase: Plastic aprons were readily available and used for every patient. Gowns not available and not required. Recovery phase: Continuous availability of aprons. Plastic aprons used for every patient contact. Gowns are not available and not required

Int_22	Immediate response phase: Gloves were readily available and were worn when seeing any patient Recovery phase: Continuous availability of gloves. Use of gloves for every patient contact	Immediate response phase: Surgical masks were readily available. Use of surgical masks for every patient seen. FFP 3 used for confirmed COVID cases and aerosol interventions Recovery phase: Continuous availability of surgical masks and FFP 3. Use of surgical masks for every patient seen and FFP 3 used for confirmed COVID cases and aerosol interventions	Immediate response phase: Eye protection available and only used on need basis (i.e. confirmed COVID cases and when carrying out aerosol interventions) Recovery phase: Continuous availability of visors and goggles and used on need basis	Immediate response phase: Plastic aprons were readily available and used for every patient. Gowns were only used for confirmed COVID cases and for aerosol interventions Recovery phase: Continuous availability of aprons. Plastic aprons were readily available and used for every patient. Gowns were only used for confirmed COVID cases and for aerosol interventions
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Figure 1. Comparing the dynamic capabilities view with supply chain resilience capabilities

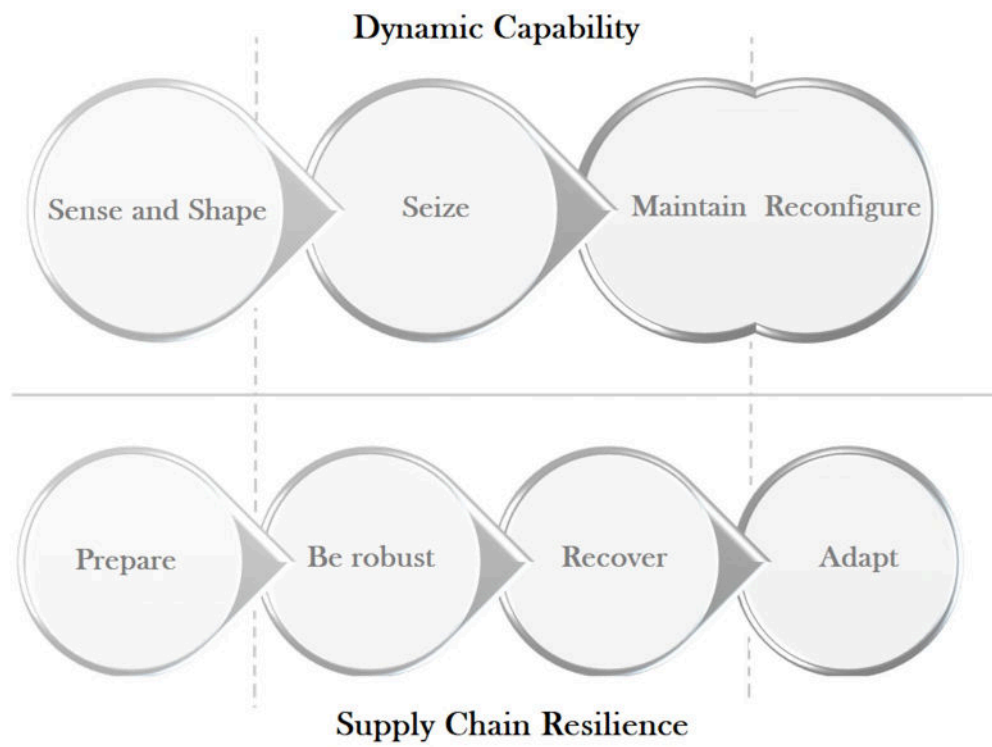


Figure 2. Summary of findings under each dynamic capability **NB:** R1 represents the recommendations made to facilitate reconfiguration of resources to improve the sensing and shaping capabilities of healthcare supply chains. R2 represents the recommendations made to facilitate reconfiguration of resources to improve the seizing and maintaining capabilities of healthcare supply chains.

