UNIVERSITY OF TURKU
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# Building Resilient Supply Chains in Industry 4.0

The case of the medical equipment industry

International Business

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Author:

Wirsiy Elizabeth Musah

Supervisors:

D.Sc. Birgitta Sandberg

D.Sc. Majid Aleem

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**Author**: Wirsiy Elizabeth Musah

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The medical equipment industry is facing a new set of challenges in the era of Industry 4.0, where supply chains are becoming more complex and vulnerable to disruptions. The research question is "How to build resilient medical equipment supply chains in industry 4.0?" The study employs a qualitative approach, including a single case study, using interviews. The study identifies the critical success factors and the main challenges faced by the medical equipment industry in building resilient supply chains. The study also presents a framework for building resilient medical equipment supply chains in Industry 4.0, which includes an interdependency of strategies to enhance the resilience of medical equipment supply chains by addressing the different phases of supply chain resilience. This thesis contributes to the existing literature by providing insights into the influence of Industry 4.0 on supply chain resilience in the medical equipment industry, and by providing practical recommendations for building resilient medical equipment supply chains.

**Key words**: supply chain resilience, industry 4.0, medical equipment industry

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# 1 INTRODUCTION

## 1.1 Background of the study

The phenomenon of interest for this master thesis is supply chain resilience, a critical component of supply chain risk management (Senna et al. 2021, 2; Ponomarov & Holcomb 2009, 130). Recently, the COVID-19 pandemic has proven that "*if healthcare supply chains break, all other supply chains break*" (Senna et al. 2021, 1) since peoples' health is affected thereby preventing them from returning to work or carrying out their jobs efficiently. The Healthcare sector has multiple suppliers who must be integrated seamlessly to generate value from the supply chain. The healthcare supply network constitutes supply of health services, medicines, medical equipment, and blood (Marques et al. 2020, 594). However, the pandemic caused a ripple effect (Ivanov 2020, 6) leading to shortages in the supply of medical equipment (Speiske et al. 2022, 2; PAHO 2000, 19).

In his case study, Gereffi (2020) discusses the severe lack of medical equipment, inadequate supply capacity and prolonged replenishment time, all of which have a huge significant impact on medical treatment. The medical equipment industry is highly regulated, and their relevance lies in their impact on the quality of social healthcare and possibility of any shortages for society (Jafarnejad et al. 2019, 817) as witnessed during the COVID-19 pandemic peaks. Industry 4.0 technologies like Internet of Things in healthcare can provide data in real time to guarantee data security and quality. Automating several recurrent activities in healthcare can reduce human error rates, thereby increasing healthcare supply chain performance (Senna et al. 2021, 4). For instance, there has been a rise in recent decades in the number and complexity of cold medicines, as well as the complexity of their global supply, prompting worries regarding maintaining enough control in the cold chain (Ojo et al. 2019).

Because of the huge and ongoing increase in demand for the goods produced by temperature-controlled industries, particularly fresh agricultural products, manufactured food, chemical reagents, and medical vaccines, the cold supply chain has taken on an increasingly significant role in the dynamic global economy of today. Because cold chain logistics causes a useful extension to product shelf life, it is regarded as a significant competitive advantage because it enables suppliers to access international markets and to satisfy the enormous local demand brought on by population increase. (Tukamuhabwa,

Mutebi & Kyomuhendo 2021, 11) Looking at the pandemic which hit many sectors hard, the health sector has been strained to limits and though we are still in the pandemic it is important to look at how supply chain resilience can be built taking advantage of the digitalization era.

It may feel like we bounced back but the pandemic is not over yet, and just like the conversation on data leakage flipped from "if" to "when" a company will be hacked (DBIR 2021, 53), same applies to supply chain disruptions. We must therefore consider more efficient and effective responses to overcome another supply chain disruption without overwhelming the health system. Ivanov and Dolgui (2021) argue that there is a need to digitalize the supply chain in other to ensure its resilience in pandemic times and event of other disruptions. Although companies have shown interest in industry 4.0 smart processes and systems, considering them as enhancers in boosting supply chain performance and resilience (Ralston & Blackhurst 2020), industry 4.0 technologies are quite new and underexplained in supply chain resilience research (Spieske & Birkel 2021, 13).

Although there is no agreed definition for supply chain resilience, its main objective is to rapidly recover from unplanned events or disruptions to its initial state or an improved performance (Ponomarov & Holcomb 2009). In their analysis of different supply chain resilience definitions, Hohenstein et al. (2015) note the focus of researchers on the response and recovery phases while paying less attention to the readiness and growth phases which are necessary for a proactive supply chain (Hohenstein et al. 2015). Supply chain resilience can be built in four different phases before and after a supply chain disruption namely readiness, response, recovery, and growth phases (Hohenstein et al. 2015). To include all four phases, Hohenstein et al. (2015, 108) propose the following definition:

> *"Supply chain resilience is the supply chain's ability to be prepared for unexpected risk events, responding and recovering quickly to potential disruptions to return to its original situation or grow by moving to a new, more desirable state in order to increase customer service, market share and financial performance."*

Most supply chains are designed to be cost efficient while neglecting resilience or agility (Christopher & Peck 2014, 8). Natural and man-made disruptions such as pandemics, union strikes, port closures, container shortages, currency changes and wars (Pettit, Fiksel

& Croxton 2010; Ponis & Koronis 2012, 923; Christopher & Peck 2014, 8; Ivanov 2020, 2) have proven this weakness in supply chains. These supply chains are mostly reactive in nature instead of anticipating unforeseen disruptive events (Hohenstein et al. 2015, 102). Hirsh (2021, 143) argues that the events of 2020 have revealed weaknesses in areas such as raw material procurement, supply chain management, and human resource practices. Thus the importance for companies to take the lessons learned from this crisis and apply them to create more resilient infrastructures for the future, rather than simply trying to rebuild what was there before. (Hirsh 2021, 143)

Considering all digital technologies under the umbrella of Industry 4.0, this revolution will inevitably involve many kinds of cutting-edge technologies such as blockchains, Internet of Things, Big Data etc. and firms should seize the opportunity of these emerging technologies to manage supply chain risks and strengthen their supply chains. The goal of implementing technology related to Industry 4.0 is to exert an influence on organisations and thereby digitally alter their business models, corporate cultures, and supply chains in order to achieve operational excellence (Ghadge et al. 2020, 680).

Popular supply chain resilience elements like flexibility, collaboration, redundancy, visibility, and agility have been identified (Hohenstein et al. 2015; Scala & Lindsay 2021). These are quite similar to those supply chain resilience enablers identified by Jafarnejad et al. (2019) in the medical equipment sector; agility, collaboration, information sharing, trust, explicitness, risk management culture, adaptability, structure and funding, and environmental conditions (Jafarnejad et al. 2019, 823-824). By continually adapting and creating skills to make the supply chain more robust, businesses can position themselves to gain a competitive advantage that is both long-term and sustainable (Ponomarov & Holcomb, 2009).

The digital supply chain makes use of newly developing intelligent technology and necessitates that all supply chain processes be hyperconnected to one another. There is a lack of research on how industry 4.0 technologies can increase resilience along the supply chain new information technologies, such as the internet of things and artificial intelligence, can increase resilience with the advent of industry 4.0. (Rha 2020, 22). A well-established route to manage supply chain risks, generate supply chain resilience and obtain supply chain performance starts from risk identification followed by assessment and then mitigation (Senna et al. 2021, 10). Factors that constitute the supply chain

resilience in industry 4.0 such as blockchain, Internet of Things, process automation, security and compliance have been identified but their importance in obtaining supply chain resilience is not known (Senna et al. 2021, 7). It will therefore be useful to contribute to the scarce literature in the recovery and growth phases of the supply chain (Spieske & Birkel 2021, 12-13).

## 1.2 Research question and structure of study

This research contributes to the industry 4.0 discussion in the medical equipment supply chain and how its emerging technologies can increase resilience during a disruption as well as prepare for future disruptive events. The study will be important for managerial practice to eliminate human error, gain full control of the supply chain and build trust and information sharing among the supply network stakeholders for efficient supply chain performance.

The research therefore seeks to answer the main question:

**How to build resilient medical equipment supply chains in industry 4.0?**

To answer the main research question, two sub questions are proposed:

1) **How does industry 4.0 enhance the supply chain resilience phases?**
2) **What strategies ensure increased resilience in medical equipment supply chains?**

The first sub question examines the different phases of medical equipment supply chain, and the impact industry 4.0 factors have on these phases. Although Supply chain resilience can be built in four distinct phases ex-ante and ex-post (Hohenstein et al. 2015), most of the research at the intersection of industry 4.0 and supply chain resilience has focused on the readiness and response phases with little done in the recovery phase and no focus on the growth phase (Spieske & Birkel 2021, 12-13). The first sub-question thus seeks to establish the effect of industry 4.0 enhanced supply chain resilience factors across the supply chain covering all four supply chain resilience phases with a focus on the recovery and growth phases. In the second sub question, I analyse the proactive and reactive management strategies implemented to ensure resilient supply chains. This will also give insights on how even during adversity or supply chain disruptions, resilient supply chains can increase company competitiveness and market share. Where companies decide to focus their resources to obtain the most critical factors especially with limited

resources or just to avoid investing more resources on less important than more important strategies are thus important to consider. This also gives room for the kind of industry 4.0 enabler technology to invest in for the future and competitive advantage of the firm.

The scope of the present study is limited to a company supply chain instead of considering specific supply chains or comparing several companies' supply chains. The organization of the rest of the study is summarized in Figure 1 below.

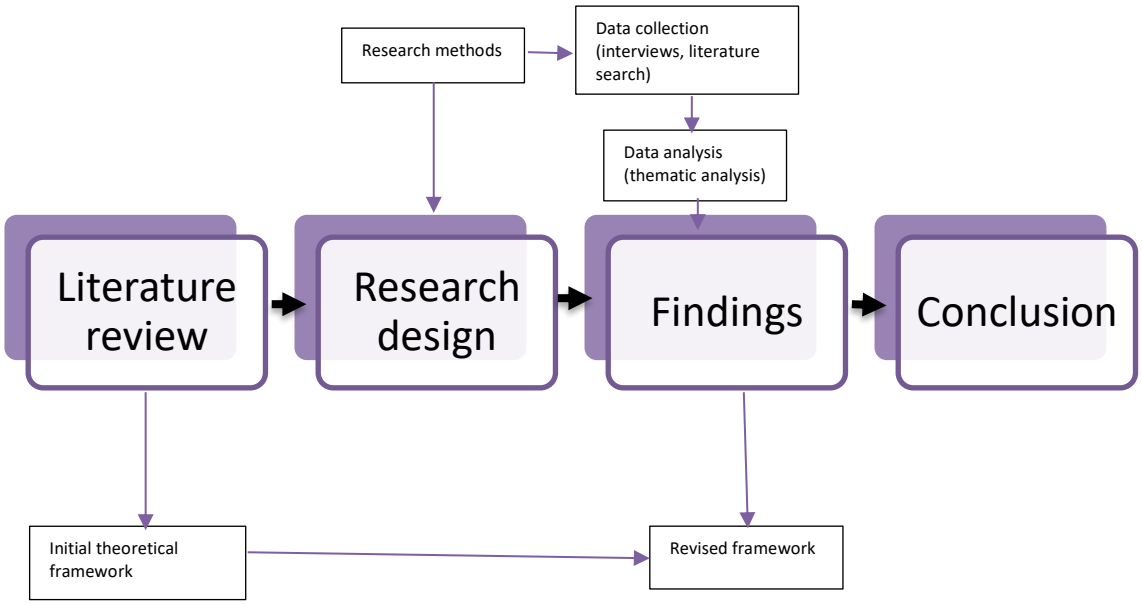


Figure 1 Structure of thesis

Firstly, there is a theoretical background (Chapter 2) which presents the concepts and past research relevant to the study which gives the basis for theoretical framework. This mainly considers literature on supply chain resilience, strategies, industry 4.0 enabler technologies, and the medical equipment supply chain. The chapter ends with an illustrated conceptual framework. Secondly, I discuss the research design (Chapter 3) which examines the research method, data collection and data analysis procedures employed. The fourth chapter discusses findings of the empirical analysis. It consists of the results and discussion after thematic analysis of data. In answering the research questions, findings are backed and/or compared with existing literature thereby linking them to theory. The final chapter (Chapter 5) comprises of the research conclusion, with theoretical and managerial contributions, limitations, and recommendations for future research.

# 2 LITERATURE REVIEW

This chapter discusses extant literature, definitions, and theories of what other researchers have said on the research subject area. Guided by the research questions, this chapter has been conveniently divided into four subsections. The first subsection gives an understanding of supply chain resilience including evolution of definition over the years and the different phases. The next subsection explores strategies to ensure supply chain resilience. Subsection three tackles the role of industry 4.0 technologies in enhancing supply chains thereby making them resilient. The fourth subsection explores the medical equipment supply chain and finally section five summarizes the theoretical background and presents the preliminary framework of the research.

## 2.1 Supply chain resilience

### 2.1.1 Evolution of definition

The concept of supply chain resilience has developed over the years (Ponomarov & Holcomb 2009; Hohenstein et al. 2015; Kamalahmadi & Parast 2016) to include different aspects and phases of resilience (Hohenstein 2015, 99). As shown in Figure 2 below, the ability of supply chains to respond to and recover from disruptions is no longer the primary focus when defining supply chain resilience; instead, the emphasis has evolved to encompass elements of resilience, preparation, and growth (Ali, Mahfouz & Arisha 2017, 22).

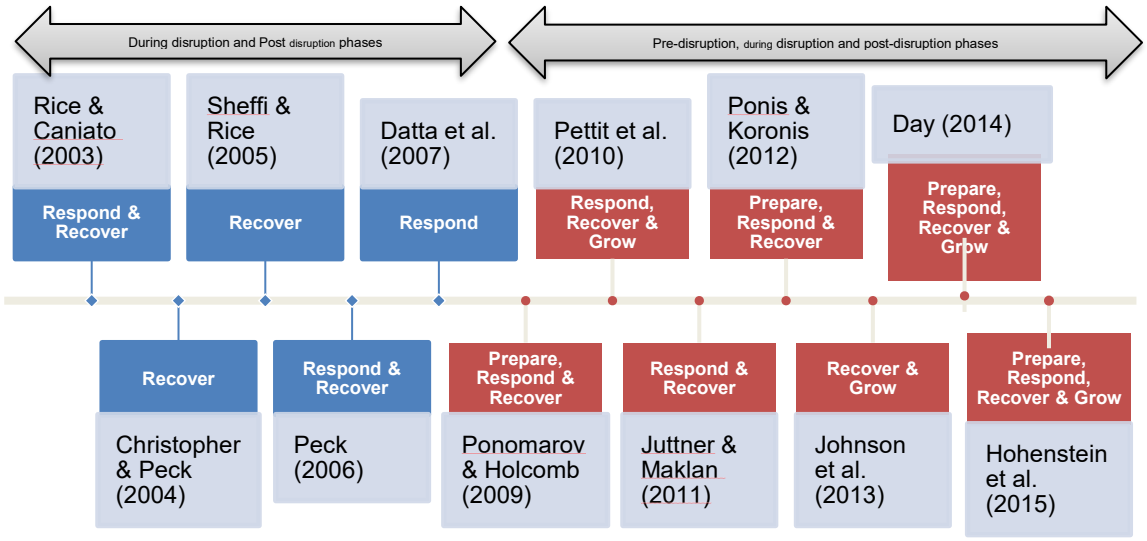


Figure 2: Supply chain resilience phases timeline in definitions (modified from Ali, Mahfouz & Arisha 2017, 22)

After the first concise definition of supply chain resilience by Christopher & Peck (2004, 2), Ponomarov & Holcomb (2009, 131) proposed the first supply chain resilience definition highlighted readiness, response, and recovery phases. This and most other subsequent definitions were considering three out of four supply chain phases. Table 1 below outlines the various definitions of supply chain resilience including all four phases.

Table 1: Supply chain resilience definitions (Hohenstein 2015, 97-100)

| Definition | Reference |
|---|---|
| Resilience is the capability of a SCN to avoid disruptions or quickly recover from failures. The capacity of a system to survive, adapt, and grow in the face of unforeseen changes, even catastrophic incidents | Klibi et al. 2010, 287 and 291 |
| Supply chain resilience is concerned with the system's ability to return to its original state or to a new, more desirable, one after experiencing a disturbance, and avoiding the occurrence of failure modes | Carvalho et al. 2012, 331 |
| Resilience refers to SC's ability to cope with unexpected disturbances. Supply chain resilience is concerned with the system ability to return to its original state or to a new more desirable state, after experiencing a disturbance, and avoiding the occurrence of failures modes | Cabral, Grilo & Cruz-Machado 2012, 4831 |
| A supply chain can thus be resilient if its original stable situation is sustained or if a new stable situation is achieved as long as the supply chain is able to "bounce back from a disruption". …A supply chain is resilient if it uses resources that enable it to cope with change. | Wieland 2013, 655 |
| The capability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change | Day 2014, 3 |
| Supply chain resilience is the supply chain's ability to be prepared for unexpected risk events, responding, and recovering quickly to potential disruptions to return to its original situation or grow by moving to a new, more desirable state in order to increase customer service, market share and financial performance. | Hohenstein et al. 2015, 108 |

Many researchers have built on and extended the supply chain resilience definition to include different phases of supply chain resilience with more focus on the response and recovery phases (Hohenstein 2015, 100). The readiness and growth phases received the least consideration and thus, Table 1 above only considers those supply chain resilience definitions that share a common perspective by addressing all supply chain resilience phases as analysed by Hohenstein et al (2015) including their own proposed overarching definition which is the preferred definition considered by this study. This is because their definition highlights the three-performance metrics (customer service, market share and

financial performance) that make it possible to report on the severity of a disruption's impact and how well a company's supply chain operates. (Hohenstein 2015, 107)

### 2.1.2 Supply chain resilience phases

Supply chain resilience is described to happen in four distinct phases happening before a disruption (Ex-ante) and after a disruption (Ex-post): readiness, response, recovery (Ponomarov & Halcomb 2009; Kamalahmadi & Parast 2016; Scholten, Scott & Fynes 2019, 439), and growth (Hohenstein et al. 2015, 96).

The *readiness phase* depicts all measures in the pre-disruption state to lower the likelihood of a disruption and lessen negative impact. This phase thus supports subsequent phases of the supply chain resilience (Hohenstein et al 2015; Spieske & Birkel 2021, 8). It is necessary to have pre-emptive capabilities, also known as preparedness, to have dynamic control over the supply chain (Chowdhury & Quaddus 2016, 712). Due to the complex and time-consuming nature of developing new products, it can be beneficial for businesses to devote extra resources to ensuring their supply chains are prepared in advance of the new product's launch (Tolonen *et al.* 2017, 237). To successfully navigate the unpredictability of modern business settings, organizations require proactive capabilities. These qualities can also be comparable to the capability of having a supply chain that is ready to withstand turmoil. Therefore, having a ready supply chain is vital to overcoming disruptive occurrences and developing the capability of resilience. Criteria such as disaster preparation, redundancy, flexibility, collaboration, and visibility are said to serve supply chain readiness. (Chowdhury & Quaddus 2016, 712)

The supply chain *response phase* represents countermeasures taken immediately after a disruption has happened. It is imperative that these actions be implemented immediately in order to prevent adverse effects on the supply chain (Hohenstein et al 2015, 101; Spieske & Birkel 2021, 8). One of the most essential characteristics for companies to have, is the ability to respond fast to the effects of the outside world, reorganise the distribution of their resources, and recover swiftly from whatever weaknesses they may have (Chowdhury & Quaddus 2016, 713).

The *recovery phase* seeks to rapidly restore the performance of the supply chain depending on the response time (Hohenstein et al 2015, 101; Spieske & Birkel 2021, 9). We consider how long it will take to recover, how much it will cost, how well it can

absorb disruption, and how well it can lessen the impact of a loss as another way to evaluate a system's resilience. Another way to evaluate a system's resilience is to consider how well it can lessen the impact of a loss. All these aspects relate to how well the system recovers after an interruption. (Chowdhury & Quaddus 2016, 713)

The *growth phase* is the goal of supply chain resilience, and its measure focuses on a new and improved supply chain performance than its initial state before disruption (Hohenstein et al. 2015, 96; Spieske & Birkel 2021, 9). The supply chain can learn from previous disruptions and use that information to improve its future performance based on the lessons it has learned (Ali, Mahfouz & Arisha 2017, 23).

## 2.2 Supply chain resilience strategies

Hohenstein et al. (2015) in their literature review, synthesized the different supply chain resilience elements into proactive and reactive strategies for the ex-ante and ex-post disruption stages respectively. Reactive strategies seek to reduce outsourcing risks which are more challenging to control, while proactive strategies are more focused on the supply chain (Saglam, Cankaya & Sezen 2020, 1227). Both proactive and reactive strategies are examples of ways that organisations can ensure they are resilient (Hohenstein et al. 2015, 101).

### 2.2.1 Proactive supply chain resilience strategy

Proactive strategies are competences required prior to a supply chain disruption i.e., readiness phase (Ali, Mahfouz & Arisha 2017, 21). The risk appetite of an organisation may influence its strategy, whereby, a risk-seeking attitude could lead to a reactive or do-nothing strategy as opposed to a proactive strategy by a risk averse organisation (Olivares-Aguila & Vital-Soto 2021, 12). To effectively deal with supply chain complexities, proactive supply chain elements must be considered in disruption management. These include efficiency, flexibility, and resilience (Gunasekaran, Subramanian & Rahman 2015, 6813). Efficiency can depend on supply chain responsiveness, and both will thus be explained in conjunction as suggested by Saglam, Cankaya and Sezen (2020, 1225). Therefore, we considered proactive strategies to include flexibility, responsiveness, and resilience (Cankaya & Sezen 2020, 1225).

#### *2.2.1.1 Flexibility*

This refers to the ability of the supply chain to react and respond to disruptions and threats (Saglam, Cankaya & Sezen 2020, 1128). It It lets firms to react more quickly and determine the optimal course of action in reaction to external environmental influences, whether those forces be good or bad (Gunasekaran, Subramanian & Rahman 2015, 6813). System, product, and process flexibility are the fundamental aspects of flexibility. Structural and strategic elements make up system flexibility while product and process flexibility are considerably used by companies (Ivanov, Sokolov & Dolgui 2014, 2157). Firms can generate a variety of items using flexible production systems without suffering time-consuming and costly changeover activities (Sodhi, Tang & Willenson 2021, 8).

As a common approach, safety stock increases flexibility in the face of demand and supply uncertainty. An organisation can use safety stock to lower the likelihood of an inventory shortage to a manageable level (Angkiriwang, Pujawan & Santosa 2014, 54).

#### *2.2.1.2 Responsiveness*

In an uncertain world, the ability of a supply chain to be agile and react rapidly to unanticipated occurrences is a significant advantage (Christopher & Peck 2014, 13). A responsive supply chain strategy's main objective is to make the focal organization more sensitive to market dynamics by proactive information sharing with its clients, supplier engagement, and use of cutting-edge manufacturing technologies (Roh, Hong & Min 2014, 208).

Responsiveness guarantees a suitable reaction and adaptability to interruptions so that the recovery process may get underway as quickly as possible after a risk event (Hohenstein et al. 2015, 107). In addition to its competitive position, the responsiveness of a company’s supply chain is an important determinant of its resilience (Sheffi & Rice 2005, 45). Suppliers are considered responsive if they can accommodate last minute changes in orders, ship products quickly and keep to agreed delivery dates (Handfield & Bechtel 2002, 379).

#### *2.2.1.3 Resilience*

Resilience has often been left out in supply chain design and Christopher and Peck (2004) have made recommendations to provide basis for designing supply chains with this in mind; (i) understanding the network connecting the suppliers and the business and

suppliers to downstream customers, (ii) supply base strategy to consider alternative supply sources, and (iii) considering design principles when reengineering supply chains (open supply strategies, strategic disposition of added capacity). (Christopher & Peck 2004, 13-16)

As an important characteristic, therefore, supply chain must be resilient to survive temporary vulnerabilities and can adapt to disruptions and thrive in the long term (Pettit, Fiksel & Croxton 2010, 13). Pettit, Fiksel & Croxton (2010) assesses supply chain resilience based on two pertinent dimensions namely capabilities and vulnerabilities. Supply chain vulnerabilities are *fundamental factors that make an enterprise susceptible to disruptions*. (Pettit, Fiksel & Croxton 2010, 6). The Table 2 below outlines the defines vulnerability factors with associated sub factors.

Table 2: Vulnerability Factors (Pettit, Fiksel & Croxton 2010, 11)

| **Vulnerability Factor** | **Definition** | **Sub-Factors** |
|---|---|---|
| Turbulence | Environment characterized by frequent changes in external factors beyond your control | Natural disasters, Geopolitical disruptions, Unpredictability of demand, Fluctuations in currencies and prices, Technology failures, Pandemic |
| Deliberate threats | Intentional attacks aimed at disrupting operations or causing human or financial harm | Theft, Terrorism/sabotage, Labor disputes, Espionage, Special interest groups, Product liability |
| External pressures | Influences, not specifically targeting the firm, that create business constraints or barriers | Competitive innovation, Social/Cultural change, Political/Regulatory change, Price pressures, Corporate responsibility, Environmental change |
| Resource limits | Constraints on output based on availability of the factors of production | Supplier, Production and Distribution capacity, Raw material and Utilities availability, Human resources |
| Sensitivity | Importance of carefully controlled conditions for product and process integrity | Complexity, Product purity, Restricted materials, Fragility, Reliability of equipment, Safety hazards, Visibility to stakeholders, Symbolic |
| Connectivity | Degree of interdependence and reliance on outside entities | Scale of network, Reliance upon information, Degree of outsourcing, Import and Export channels, Reliance upon specialty sources |
| Supplier/Customer disruptions | Susceptibility of suppliers and customers to external forces or disruptions | Supplier reliability, Customer disruptions |

Vulnerabilities have a negative connotation and are influenced by factors such as turbulence, deliberate threats, external pressures, resource limits, sensitivity, connectivity and supply or customer disruptions (Pettit, Fiksel & Croxton 2010, 11). The sub factors represent measurable attributes of vulnerability according to the Pettit, Fiksel and Croxton (2010, 11). These weaknesses are brought about by forces of change, which may originate from within or outside the organisation or supply chain. Creating a state of equilibrium between investment and risk can be accomplished by increasing supply chain resilience through the development of capabilities. There are connections between each vulnerability and a particular set of skills, each of which has the potential to improve balanced resilience in a direct way. (Pettit, Fiksel & Croxton 2010, 6-7; Pettit, Croxton & Fiksel 2019, 63)

Capabilities on the other hand are "*attributes that enable an enterprise to anticipate and overcome disruptions*" (Pettit, Fiksel & Croxton 2010, 6). Capability factors are defined in Table 3 with their respective sub-factors.

Table 3: Capability factors (Pettit, Fiksel & Croxton 2010, 12)

| **Capability Factor** | **Definition** | **Sub-Factors** |
|---|---|---|
| Flexibility in sourcing | Ability to quickly change inputs or the mode of receiving inputs | Part commonality, Modular product design, Multiple uses, Supplier contract flexibility, Multiple sources |
| Flexibility in order fulfillment | Ability to quickly change outputs or the mode of delivering outputs | Alternate distribution channels, Risk pooling/sharing, Multi-sourcing, Delayed commitment, Production postponement, Inventory management, Re-routing of requirements |
| Capacity | Availability of assets to enable sustained production levels | Reserve capacity, Redundancy, Backup energy sources and communications |
| Efficiency | Capability to produce outputs with minimum resource requirements | Waste elimination, Labor productivity, Asset utilization, Product variability reduction, Failure prevention |
| Visibility | Knowledge of the status of operating assets and the environment | Business intelligence gathering, Information technology, Products, Assets and People visibility, Information exchange |
| Adaptability | Ability to modify operations in response to challenges or opportunities | Fast re-routing of requirements, Lead time reduction, Strategic gaming and simulation, Seizing advantage from disruptions, Alternative technology development, Learning from experience |
| Anticipation | Ability to discern potential future events or situations | Monitoring early warning signals, Forecasting, Deviation and Near-miss analysis, Contingency planning, Preparedness, Risk management, |

| | | |
|---|---|---|
| | | Business continuity planning, Recognition of opportunities |
| Recovery | Ability to return to normal operational state rapidly | Crisis management, Resource mobilization, Communications strategy, Consequence mitigation |
| Dispersion | Broad distribution or decentralization of assets | Distributed decision-making, Distributed capacity and assets, Decentralization of key resources, Location-specific empowerment, Dispersion of markets |
| Collaboration | Ability to work effectively with other entities for mutual benefit | Collaborative forecasting, Customer management, Communications, Postponement of orders, Product life cycle management, Risk sharing with partners |
| Organization | Human resource structures, policies, skills and culture | Learning, Accountability and Empowerment, Teamwork, Creative problem solving, Cross training, Substitute leadership, Culture of caring |
| Market position | Status of a company or its products in specific markets | Product differentiation, Customer loyalty/retention Market share, Brand equity, Customer relationships, Customer communications |
| Security | Defense against deliberate intrusion or attack | Layered defenses, Access restrictions, Employee involvement, Collaboration with governments, Cyber-security, Personnel security |
| Financial strength | Capacity to absorb fluctuations in cash flow | Insurance, Portfolio diversification, Financial reserves and liquidity, Price margin |

Instead of just reacting to the conditions of the market, firms that want to expand and acquire a competitive advantage must be able to adapt to changing circumstances and develop new capabilities. It is the responsibility of management to reconsider the proactive measures they use for their supply chain, considering both capability and vulnerability factors (Pettit, Fiksel & Croxton 2010, 12).

### 2.2.2 Reactive strategies

It would appear that the phases of responding to a risk occurrence and recovering from its effects are both fundamental and reactive components of resilience. Therefore, both dimensions are typically included in supply chain resilience definitions, and their importance is usually emphasised in these descriptions (Hohenstein et al. 2015, 101). Reactive strategies are employed in response to a disruption in the post ante phases (response, recovery, and growth) comprising of collaboration, agility, human resource management, flexibility, and redundancy (Hohenstein et al. 2015, 108). Depending on the reactive strategy, Ali et al. (2021, 97) have used cost and time factor to assess their implementation with human resources management being the only strategy at low cost and time consuming to acquire.

#### *2.2.2.1 Agility*

Agility in the supply chain involves the capability of the supply chain to react quickly and effectively to unanticipated fluctuations in demand or supply. Because their reaction times to shifts in customer demand or disruptions in supply are too slow, many companies are exposed to potential danger. There are many facets to agility, and it is just as much of a function of networks as it of individual businesses, therefore, having agile partners both upstream and downstream is an essential component for agile response. (Christopher & Peck (2004, 18)

An agile supply chain is characterised by visibility and velocity (Christopher & Peck 2004, 19). Supply chain actors have the ability to view the entire supply chain and be informed of the system's environment and key assets (Adobor & McMullen 2018, 1456). To ensure supply chain visibility, companies can develop monitoring programs such as business continuity planning, information sharing and transparency with supply chain stakeholders (Adobor & McMullen 2018, 1457).

#### *2.2.2.2 Redundancy*

Redundancy creates additional capacity that can be employed in the event of an interruption, thereby boosting responsiveness and flexibility (Adobor & McMullen 2018, 1458). Supplier backups improves flexibility by allowing the use of multiple suppliers. Though it is generally expensive for businesses to keep multiple suppliers to guarantee availability, it is dangerous to work with just a single provider (Angkiriwang, Pujawan & Santosa 2014, 54).

Capacity buffer is another way to cope with a disruption. It is expensive to adaptively the capacity level, and in order to gain flexibility, businesses set higher demand (Angkiriwang, Pujawan & Santosa 2014, 54). Businesses are able to improve the availability of their materials and become more flexible in their capacity to respond to customer demand as a result without having to increase their inventory or their costs (Angkiriwang, Pujawan & Santosa 2014, 55; Sheffi & Rice 2005, 44).

#### *2.2.2.3 Collaboration*

Collaboration refers to the capacity to work productively with other entities for the purpose of maximising individual and collective gain (Pettit 2010, 12). The fundamental idea behind the term "collaboration" and the various ways in which it can be interpreted

is that individual businesses are unable to compete successfully, which is why they must form relationships with other participants in the supply chain (Singh, Garg & Sachdeva 2018, 156). Partnerships in the supply chain are resource-intensive ventures that carry a high level of risk on both the financial and the strategic fronts (Maheshwar, Kumar & Kumar 2006, 279). Because the various partners of a supply chain cannot compete successfully against one another on their own, a continuous and dynamic system of supply chain is required. This system must allow all partners to participate in the unified system, bringing them closer to one another and encouraging them to work together. (Singh, Garg & Sachdeva 2018, 156)

When compared with businesses that carry out their operations on an individual basis, organisations that use supply chain collaboration methods enjoy a significant competitive advantage. The benefits of cooperation come in the form of increased efficiencies and effectiveness, such as lower costs across the whole supply chain in comparison to firms that do not engage in collaborative supply chain practises (Singh, Garg & Sachdeva 2018, 150). Companies work together to generate a mutually beneficial outcome by sharing information, processes, risks, and rewards (Singh, Garg & Sachdeva 2018, 151).

In their systematic literature review, Singh, Garg & Sachdeva (2018, 160-162) identify various supply chain collaboration drivers necessary to implement collaboration in the supply chain, with proceeding benefits. Drivers such as technology, trust, relationship promoter, adaptations, competition, commitment, business strategy, collaborative communication, collaboration level, cooperation, better info sharing, knowledge sharing, joint decision making, resource sharing etc. (Singh, Garg & Sachdeva 2018, 160) favour supply chain collaboration. Supply chain collaborators thus stand to benefit on time delivery, faster inventory turns, product availability, increased revenues, supply chain cost reduction, responsiveness etc. (Singh, Garg & Sachdeva 2018, 162). When there is a disruption in the supply chain, a company's performance is better and response time is shorter if supply chain partners work together (Hohenstein 2015, 110).

Supply chain collaboration has been classified into vertical, horizontal, and lateral collaboration (Soosay, Hyland & Ferrer 2008, 162). Organizations that produce products that are either identical to one another or distinct components of the same product can form horizontal alliances to work together more efficiently. Additionally, horizontal integration may take place between a group of suppliers who all serve the same consumer,

or it may involve the formation of cooperative buying groups with the goal of lowering operational expenses (Manning & Baines 2004, 822). When participants in a supply chain work together toward a common goal of improving the supply chain, a vertical collaboration might arise. In order to obtain greater flexibility in the lateral cooperation, it is intended that a combination of horizontal and vertical collaboration is utilised (Singh, Garg & Sachdeva 2018, 157).

#### *2.2.2.4 Human Resource Management*

Whether or not a company is able to successfully collect, assimilate, and use information and expertise from its supply chain partners will depend on the human resource management practises that are in place. These practises are intended to provide employees with the knowledge and motivations they need to be successful in their roles. (Haq, Gu & Huo 2020, 553).

Gowen and Tallon (2002, 39) suggest that a participatory involvement of managerial and employee support may be necessary to improve the efficiency of employee training, to increase success of supply chain practice. Even if competitors have successfully implemented supply chain management methods, Gowen and Tallon (2002, 42) recommend various other ways to achieve a competitive edge by using human resource management factors.

## 2.3 Industry 4.0 enabler technologies

According to Spieske and Birkel (2021, 9), there is a positive relationship between industry 4.0 technologies and supply chain resilience indicators demonstrated by the industry 4.0 supply chain resilience framework (Figure 3). According to Ivanov et al. (Ivanov et al. 2019, 838) "*Today and looking at near future, the supply chain will be as good as the digital technology behind it*" and we consider all digital technologies under the canopy of industry 4.0.

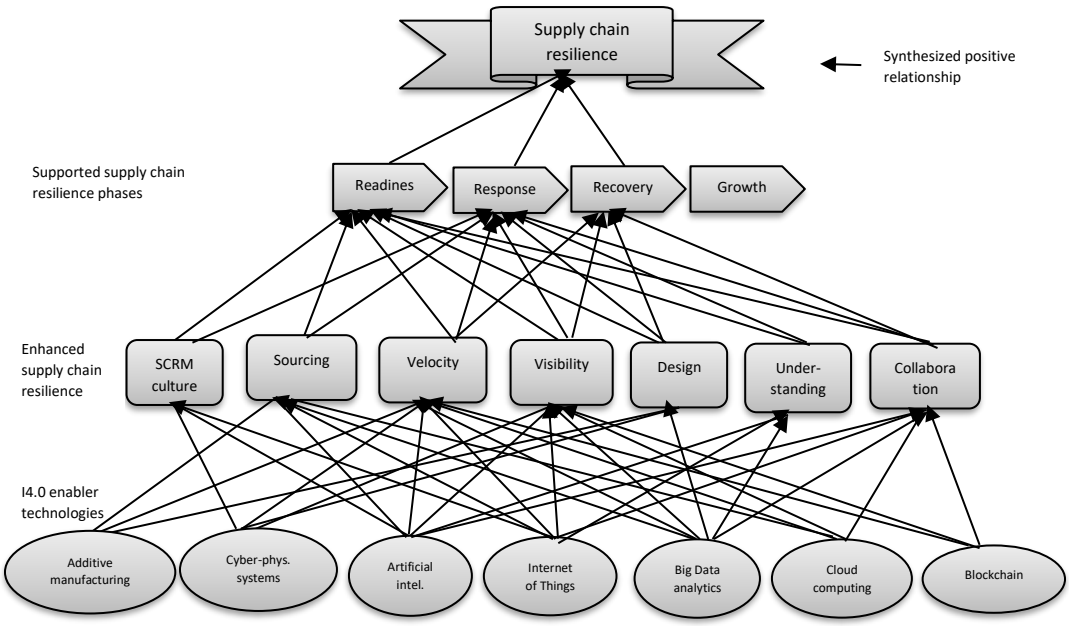


Figure 3: Industry 4.0 supply chain resilience framework (modified from Spieske & Birkel 2021, 8)

The framework in

Figure 3 shows the influence industry 4.0 technologies have on supply chain resilience factors such as visibility, design, collaboration, sourcing etc. As a result, these factors improve the supply chain resilience phases before and after a disruption. Although these identified technologies have an influence on all identified supply chain resilience antecedents, relating to more than one, the growth stage is completely left out. There is no identified technology and relating factor supporting the growth phase.

Industry 4.0 is an automated network of machines and products that is the result of intelligent networking (Ivanov et al. 2019, 831). In their exploratory study, Ralston and Blackhurst (2020) confirm that not only does industry 4.0 improve supply chain performance but also enhances supply chain resilience in a disruption. Industry 4.0 data analytics applications enable informed decision when managing severe supply chain disruptions (Ivanov & Dolgui 2021, 784). Nonetheless implementing industry 4.0 comes with both threats and opportunities for future supply chains (Ghadge et al. 2020). The implementation and utilisation of intelligent devices are at the heart of Industry 4.0 (Kumari et al. 2018, 1).

### 2.3.1 Industry 4.0 drivers and barriers

Ghadge et al. (2020, 675) groups drivers and barriers for implementing industry 4.0 in supply chain into four business dimensions i.e., organizational, strategic, technological, and legal and ethical dimensions as shown in the Table 4 below. The executives in charge of supply chains need to revise both their understanding of and attitude toward Industry 4.0 to ensure that the digital transformation of supply chains goes off without a hitch. This can be accomplished by considering both the forces that are driving them to implement Industry 4.0 and the obstacles that stand in their way. (Ghadge et al. 2020, 675). There is a strong correlation between a company's propensity to implement Industry 4.0 and the opportunities and obstacles associated with doing so. Companies of different sizes, in different industries, and with different roles in Industry 4.0 face different sets of drivers and barriers. (Müller, Kiel & Voigt 2018, 13)

Table 4: Drivers and barriers for adoption of industry 4.0 in supply chains (Ghadge et al. 2020, 675)

| **Business dimensions** | **Drivers** | **Barriers** |
|---|---|---|
| Organisational | (1) Increased efficiency<br>(2) Cost reduction<br>(3) Higher quality<br>(4) Agility<br>(5) Load balancing and stock reduction | (1) Financial constraints<br>(2) Lack of management support<br>(3) Resistance to change<br>(4) Lack of digital vision and strategy<br>(5) Lack of expertise<br>(6) Complex network systems |
| Legal and ethical | (1) Reduction of monotonous work<br>(2) Reduction of environmental impact | (1) Legal issues<br>(2) Problems related with coordination<br>and collaboration<br>(3) Data privacy and security issues |
| Strategic | (1) New Business models<br>(2) New value offers for enhanced competitiveness | (1) Profiling and complexity issues<br>(2) Lack of policies and support from the government<br>(3) Lack of research and development<br>(4) Unclear economic benefits<br>(5) Lack of digital culture |
| Technological | Transparency | (1) Lack of digital infrastructure<br>(2) Poor data quality and management |

One of the things driving Industry 4.0 is the emergence of new business models, which in turn is facilitated by increased competitiveness in the strategic business dimension. A lack of policies makes it difficult to conduct R&D, assess economic advantages, and consequently, a lack of digital culture, all contribute to an increase in the difficulty of implementing Industry 4.0. Data security difficulties, which in turn raise legal and ethical concerns, are a direct result of the growing difficulty in coordinating and collaborating. From a technological standpoint, it is difficult to access high-quality data due to a lack of digital infrastructure. (Ghadge et al. 2020, 677) From a business's point of view, the efficiency of adopting Industry 4.0 is hampered by a lack of managerial support and a lack of digital vision. One of the obstacles to creating high-quality, effective applications of Industry 4.0 technology is a lack of funding (Ghadge et al. 2020, 677; Herceg et al. 2020, 14).

### 2.3.2 Contribution of industry 4.0 to supply chain resilience

Ghadge et al. (2020, 682) believe that it is self-evident that the traditional supply chains urgently require a transformation through the implementation of the concepts of Industry 4.0 to survive in the quickly changing markets. To adopt and participate in the new revolution, businesses are looking further outside than the confines of the supply chain. (Ghadge et al. 2020, 682) The processes involved in supply chains are rapidly becoming more computerised, automated, and adaptable because of these advancements. The effects of Industry 4.0 can be seen and felt in all levels of supply chains, as well as in the tactics used for supply chain management. (Ghadge et al. 2020, 672)

In their scoping review, Tortorella et al. (2021) identify 12 industry 4.0 ICTs that contribute to supply chain resilience: Enterprise Resources planning, Big Data, Radio Frequency identification (RFID), Internet of things (IoT), Sensors, Cloud computing, Cyber physical systems, blockchain, augmented and virtual reality, additive manufacturing, digital twin, and machine learning. It is important to note that these technologies need to be interoperable with each other (Frederico 2020, 99).

*Enterprise Resource Planning (ERP)* refers to information solutions that aim to integrate and make the most of an organization's available resources (Oztemel & Gursev 2018, 154). Its usage has transitioned from managing physical assets to managing company knowledge (Irfan et al. 2022, 1156). ERP software helps a business integrate sales,

accounting, production, human resources, stock management, and purchasing operations and data. As a result, ERP systems offer a holistic strategy for data utilization. (Oztemel & Gursev 2018, 154)

*Additive manufacturing or 3D printing* uses 3D printers at different stages of the supply chain to increase production flexibility, shorter lead times, increase product individualization and reduce inventory. Just like the Adidas Speedfactory, companies can use 3D printing to automate production processes and bring production closer to customers thereby eliminating the problem of storing goods in warehouses since production is local and fast, and increasing efficiency. (Ivanov et al. 2019, 832) In order to boost supply chain responsiveness and efficiency, additive manufacturing could be considered. This manufacturing technique would allow for mass-customized production (Frederico 2020, 98).

*Internet of Things (IoT)* has completely transformed the internet communication industry, and its application in medical care is proving to be highly advantageous in spite of the many obstacles that exist (Joyia et al. 2017, 244). The Internet of Things makes it easier for different parts of the supply chain to communicate with one another by connecting the many physical devices and computer systems that make up the chain. (Oztemel & Gursev 2018, 154).

*Sensors* through the processing of data from physical sources and the provision of data in real time can aid in providing capacity and parametric inventory inputs to simulation and optimisation models for supply chain recovery simulations taking into account available resources in the non-disrupted supply chain (Ivanov & Dolgui 2021, 779).

*Machine Learning* quickly become the go-to method for generating usable software for applications such as computer vision, audio recognition, natural language processing, robot control etc. Its impact is not limited to the field of computer science, but it has also been felt in many other sectors focused on data-intensive problems, such as those dealing with customer service, fault detection in complex systems, and logistics management. (Jordan & Mitchell 2015, 255).

The combination of computing and physical processes is referred to as *Cyber Physical Systems (CPS)*. These Cyber Physical Systems are crucial components of Industry 4.0 deployments. They incorporate imaging and control capabilities into the respective

systems. The ability of these systems to respond to any feedback that is generated is a significant feature. They make it possible to immediately control and check the feedback from the process for the purpose of producing the intended results. (Oztemel & Gursev 2018, 141)

*Advanced tracking and tracing (T&T)* systems identify and alert deviations or any other dangers in a supply chain. These systems can be supported by RFID technology to communicate supply chain vulnerabilities to other levels to revive the initial processes. T&T systems can thus be used in the reactive stage to monitor and identify supply chain disruptions (Ivanov et al. 2019).

*Digital twin technology* is a combination of advanced digital technology like Cyber physical system, additive manufacturing, Big Data, IoT and wearables. It connects the virtual (cyber world) and physical worlds to present the state of the network at any given time including any obstacles. Hence digitalizing the supply chain ensures control, optimization, and simulations of interruption scenarios thereby, providing informed decision making to improve supply chain resilience. (Zheng et al. 2021)

*Big Data* extracts knowledge and information from large amounts of data (Ivanov et al. 2019; Frederico 2020, 99). In supply chain resilience, big data connects to all kinds of data sources, ingest the released data, interconnects the data together, perform big data analysis and finally, visualize the data to users. It exposes valuable information to improve supply chain elasticity and enhance supply chain resilience especially during disruptions. (Zheng et al. 2021, 247) Supply chain managers can make quicker and more confident decisions in the face of a disruption if they have access to big data analytics (Frederico 2020, 99).

*Augmented and virtual reality* together, have given rise to this new technology, which holds a significant place in today's industrial society. These techniques offer a wide range of benefits, most notably in the product and manufacturing system design fields. It is possible to use it to arrive at significant conclusions regarding financial choices. It is now obvious that using simulation software is a significantly more efficient way to arrive at the best solution. (Oztemel & Gursev 2018, 151) Implementing AR in manufacturing improves process visibility, increases proactiveness, solves machine and process problems and ultimately shortens setup and maintenance periods (Frederico 2020, 98).

*Blockchain* is a distributed ledger technology that allows users to record and verify transactions involving digital assets on a decentralised, peer-to-peer computer network. With the complexity nature of supply chains, blockchain provides a great tool to identify potential vulnerabilities and assess risk levels of the supply chain (Zheng et al. 2021, 247). Any modification in the blockchain is recorded and cannot be tampered with. This increases supply chain resilience by increasing transparency and trust. Transparency, traceability, and security are characteristics that when combined, produce a dependable and reliable supply chain (Frederico 2020, 99). Zheng et al. (2021) elaborates the strong effect of integrating a combination of digital technologies (digital twin, big data and blockchain) to increase supply chain resilience instead of using them individually.

In *Cloud Computing*, cloud systems are remote servers that hold large volumes of data that has been acquired from a wide variety of business systems, devices, equipment, and sensors. This data may be accessed and used whenever it is needed. Cloud computing makes it possible to retrieve vast amounts of data in real time as well as access large amounts of data. There is a need for improved data exchange between different organisational departments, supply chains, locations, and across the boundaries of companies and other organisations. Computing environments that make use of the cloud are undergoing fast change and are a primary driver of more data-driven and intelligent supply chain activities. (Oztemel & Gursev 2018, 145) As industry 4.0 technologies continue to revolutionize various industries, it is important to consider their impact on the medical equipment supply chain and how they can be leveraged to improve its efficiency and effectiveness.

## 2.4 Medical equipment supply chain

The medical equipment supply chain experienced a lot of disruptions during the pandemic. Essential medical equipment during the pandemic included supplies like test kits, vaccines, personal protective equipment (PPE), ancillary supplies (needles, syringes, diluents), and ventilators (Scala & Lindsay 2021). For some of these supplies that relied on international suppliers and manufacturing in low labour cost economies like China, and distribution hubs in Europe, customers were forced to turn to alternatives (Scala & Lindsay 2021, 679). Lockdowns at international borders opened an opportunity for companies to think of onshore productions rather than rely solely on companies based abroad who were also affected by the pandemic (Scala & Lindsay 2021,). The medical

equipment supply chain can create capabilities that will ensure its continued existence in the long term thereby protecting itself from risks (Pettit, Croxton & Fiksel 2019, 63).

Using the grounded theory approach, Bastani et al. (2021, 8) identified wasting of both resources and time as the main factor of resilience in a medical equipment supply chain. As a supply chain risk, the pandemic has three distinct features from other type of supply disruptions: there is a risk of long-term disruption of an unpredicted scale (ii) the risk of disruptions spreading around in the supply chain and the spread of epidemics among populations is uncertain and random, and (iii) interruptions occurs simultaneously throughout the process from the supplier to the end user (Zheng et al. 2021, 240).

In the healthcare supply chain, technologies such as blockchain and the Internet of Things are finding applications. These applications are helping to evolve healthcare from version 3.0 to version 4.0, which will include advancements such as fog and cloud computing for data storage and the Internet of Things for data collection. (Senna et al. 2021, 6). Soon, cyber care will have made it possible to provide most of the care at home, leaving "super hospitals" as the only option for patients who require extremely specialised treatment (Javdani & Kashanian 2018, 43).

Relevant applications of Internet of Things services and technologies in healthcare, so called Internet of Medical Things have been illustrated in the literature review by Joyia et al. (2017). These applications make it possible for medical professionals and hospital staff to work more precisely and actively with less effort and intelligence, allowing for remote health monitoring of patients whose conditions are not life-threatening to be performed at home and thereby reducing the need for hospital resources (Joyia et al. 2017, 240). With a thorough understanding of the complexities facing the medical equipment supply chain, we are now ready to develop a preliminary framework to guide our approach to optimizing and improving the supply chain processes.

## 2.5 Preliminary framework

So far in the literature, industry 4.0 influences three out of four supply chain resilience phases i.e., the readiness, response, and recovery phases but not the growth phase as demonstrated by Spieske & Birkel (2021, 12) in their industry 4.0 Supply chain resilience framework. These four phases are characterized by two resilience elements namely proactive and reactive supply chain resilience strategies (Hohenstein et al. 2015) in which

activities are either planned for implementation before or after a disruption. The theoretical framework shown in Figure 4 guides this study.

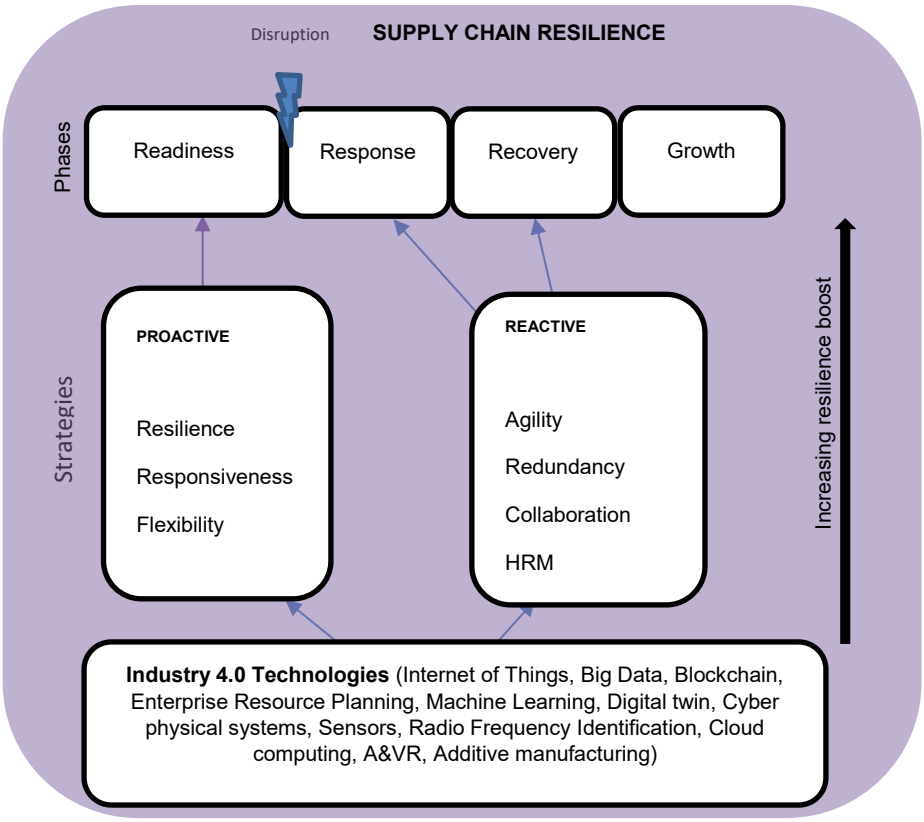


Figure 4: Preliminary framework

Ensuring that the supply chain is ready to withstand potential risks and disruptions typically demands investments which can be difficult to quantify. A resilient company may never know what kind of disruption or damages it has averted or reduced as a result of investing in its system's resilience (Pettit, Croxton & Fiksel 2019, 62). While proactive strategies are implemented in the readiness phase, it does not necessarily mean that the rest of the supply chain phases will not happen. Reactive strategies have their role to play once a disruption has occurred. Therefore, a combination of both proactive and reactive strategies is required for effective resilient supply chains. In the case of a disruption, the supply chain is able to undergo each of the phases and bounce back even more performant than its previous state.

Considering a company that only waits till a disruption occurs before it begins to implement strategies, it is a lot more difficult to for the supply chain to bounce back. According to Pettit, Croxton and Fiksel (2019, 57), an organization with high vulnerabilities and insufficient skills may encounter disruptions and spending money on

capabilities that aren't compatible with the risks they're exposed to could reduce revenues without boosting resilience.

Considering the difference in industries, and the fact that medical equipment is liable to regulations which may vary from country to country, companies might decide to implement some digital technologies and not others whereas implementing a combination of these technologies could have an astounding effect on the firm's supply chain resilience. Additionally, resistance to change, an absence of digital vision, and the exchange of data are some of the hurdles that must be overcome in order to execute industry 4.0. (Ghadge et al. 2020, 675)

Even though the manufacturers of medical equipment switched to domestic production (Scala & Lindsay 2021) in order to avoid total reliance on companies located in other countries, it is unclear whether or not this was the best decision for these manufacturers, particularly in terms of long-term viability, given that offshore productions are typically more cost effective (Cranfield University 2002, 3). When it comes to the supply chains for medical equipment, time and resources are of the utmost importance; as a result, businesses have no choice but to concentrate their efforts and resources on the most important resilience components (Bastani et al. 2021, 8-9). This means that in the digital era for example, these firms need to be open to innovative strategies and invest in the most efficient and effective technologies as medical equipment take too long to get launched and they could even be obsolete by the time they are getting out into the markets. Taking advantage of the time and events to stay in competition and gain new markets and customers is a great way to improve supply chain performance after a disruptive event (Knemeyer et al. 2003; Rice & Caniato 2003).

# 3 RESEARCH DESIGN

This chapter explores the methodology used in answering the research questions with justifications. It also describes how the researcher's consideration for trustworthiness of study. This chapter thus addresses aspects including theoretical reading methodological decisions, empirical data collection and analysis while ending with an evaluation of study for its ability to produce worthy findings.

## 3.1 Research approach

Research philosophy and methods for generating new information through research are connected to all research procedures. The philosophical position for this study stems from my personal conviction that no two similar realities exist, and perceptions and experiences may change over time and context for different people. This view falls under interpretivism and constructionism which are both concerned with subjective and shared meaning (Eriksson and Kovalainen 2015, Interpretivism and constructionism section). The ability to contextualize thus lies within the philosophical orientation of the research (Welch 2011, 742). The researcher seeks to understand supply chain resilience from individual perspectives by making sense of the emerging themes. These themes will be indicative of the common practice in supply chain resilience and used to compare with available supply chain resilience theory. Among the research methods being used today, qualitative, and quantitative are the most common (Creswell, 1995).

Deciding on which approach is suitable for research depends on the kind of data to be collected, how it is interpreted, and whether this data fulfils the research objective. Quantitative research uses numbers and statistical tools to test a hypothesis and explores the relationship between variables. Qualitative research on the other hand is based on a small sample, explores the relationship between entities and is based on findings expressed as non-standardized text which can be classified into categories, coded using a designated software (Saunders, Lewis & Thornhill 2009). Qualitative research seeks interpretation of text beyond just the literal meaning (Welch et al. 2011, 743).

Although supply chain resilience has been popular in research in recent years and even now in the Covid-19 pandemic era, there is still little researched on the recovery and growth stages (Hohenstein et al. 2015). The choice of method is determined by the researcher on where or not to specify the type of information sought after in advance or

identify concepts emerging from research participants (Creswell 2003). This thus necessitates the need to explore and understand supply chain resilience phenomenon in the medical equipment context using an inductive qualitative approach. A qualitative approach allows for in-depth understanding of richness and complexity (Malhotra et al. 2017, 183) in real life context such as in medical equipment supply chains. Several types of qualitative approaches include ethnographic, case study, grounded theory, narrative etc. and participant observations, open interviews, focus groups and case studies require close or intense contact or some form of access to the organization or group under consideration (Eriksson and Kovalainen 2015, Part III Qualitative Research Approaches section).

The selected strategy for this research is a qualitative exploratory theory building using case study (Eisenhardt 1989). According to Yin (2003), *"a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context especially when boundaries between phenomenon and context are not clearly evident"* (Yin 2003, 13*).* The following three conditions are therefore considered when choosing case study as a research strategy: (a) type of question posed, (b) extent to which researcher has control over events, and (c) degree of focus on contemporary events (Yin 2003, 5). The current study answers a "How" question with the researcher having little control over events, and the research focuses on supply chain resilience, a current trend in a real-life context, thereby fulfilling conditions stipulated by Yin (2003, 9).

Although case studies have been attacked for their lack of scientific rigour, their capacity to reduce complex themes in an approachable, vivid, personal, and straightforward format has contributed to their increasing appeal in qualitative research (Eriksson & Kovalainen 2015, Business-related case study research section), in addition, their depth and contextualization serve as a springboard for theoretical understanding (Piekkari & Welch 2018, 352). The extent of generalization will always be constrained, and variances will always be explained in terms of their context (Welch et al. 2011). First order analysis (one that uses informant-centric terms and codes) and second order analysis (one that uses researcher-centric concepts, themes, and dimensions) must be used to rigorously connect facts and theory in order to construct theory (Gioia et al. 2013, 18) and then make sense out of it.

According to Stake (1995), a prominent advocate of interpretive sensemaking, “particularity” and not generalization is the goal of case studies. This means that each case is unique and should be understood in its entirety. Because it recognizes how the social context gives human action significance, the use of "thick description" strengthens the case study (Stake 1995). This contrasts with the inductive theorizing with a positivist philosophical position, which places little emphasis on context, treating it descriptively rather than analytically (Welch et al. 2011, 755). While there is no ideal number of cases to be considered, multiple cases are preferred over single cases with four to ten cases working well, less than four cases making theory generation very difficult and more than ten cases providing complex and voluminous data (Eisenhardt 1989, 545). The case considered for this study is a manufacturing company in medical equipment (instruments, reagents, test kits etc.). The research onion (Figure 5) presented by Saunders, Lewis & Thornhill (2009, 102) has been adapted to indicate the main choices of the research design to tackle the research questions.

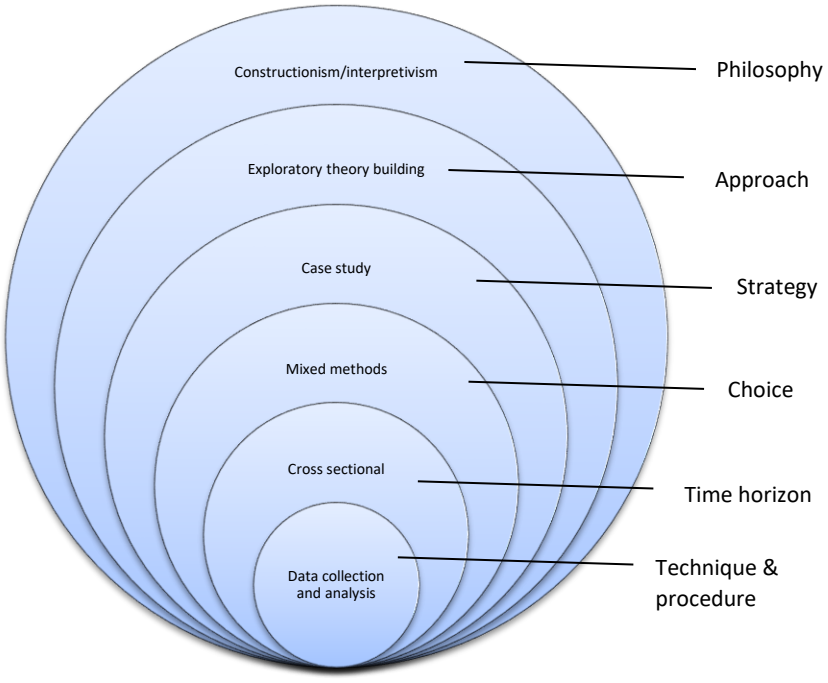


Figure 5: The research 'onion' (Adapted from Saunders, Lewis & Thornhill 2009, 102)

The research onion in Figure 5 summarizes the philosophical stand to be constructivism/interpretivism, and the inductive research approach using case study. Data collection and analysis is at the core of this section. A mixed method of data collection has been used and it was a one-time collection (cross sectional) as opposed to longitudinal data collection where the data is collected over a long period of time.

## 3.2 Selection of case company

Selecting the case company is driven by the events of Covid-19 which though came as a big shock at first, complicating and straining the supply chain, allowed the medical equipment manufacturer to test their equipment and eventually launch new products within a very short time. There is the possibility to look at the supply chain resilience from the perspective of a globally operating medical equipment manufacturer who needs to protect its value creation with its customers, manage supply chain disruption risks, gain resilience, and create new opportunities. Rethinking the supply chain disruption thus gave an opening to turn resilience into a market opportunity. The study is hence considering a case company and its supply chain. This case is thus interesting to delve into the problems and opportunities that stem from developing supply chain resilience from the medical equipment perspective.

Because qualitative research does not attempt to statistically generalize its findings, there is no need for certain sampling methodologies that were established specifically for this purpose. The selection of study subjects for qualitative investigations is purposeful, as opposed to being representative and random as it is in the case with quantitative research. (Eriksson & Kovalainen 2015, Identifying research participants section) Resilience will not only help the company prevent future disruptions, but these disruptions in the value chain will help resilient firms to gain competitive advantage and market share. Additionally, industry 4.0 is a relatively new concept in the field of supply chain resilience research; nonetheless, its use in the supply chain for medical equipment is thought to be of the utmost importance both during the epidemic and in the event of future disruptions.

To collect empirical data relevant to the study, a medical equipment manufacturing company referred to here as “Company X” was selected. They provide products, services and solutions for diagnostics, life sciences and applied markets. Their wide variety of raw materials are sourced from both domestic and international suppliers. Some critical raw materials for some principal products only have a limited or single supply and the company sometimes must procure these raw materials in large quantities in anticipation for future production needs (Case company report 2020, 12).

Like many supply chains in other sectors, the negative effects of the pandemic have been felt and may continue to linger, thereby impacting company finances, operations, and business in general. The difficulty in predicting the end of the pandemic may continue to impact the company (for example inability to ship and/or receive products, reduced profitability, stock price fluctuations due to market volatility, workforce absenteeism and distraction; labor shortages; customer credit concerns etc.) (Case company report 2020, 17).

Another factor that may affect business operations is keeping up with technology to stay in competition. This necessitates constant research and development of novel, trustworthy technologies and applications, as well as timely, adequate production and distribution. Failure to do so will lead to wastage of resources, loss of market share and potential revenue (Case company report 2020, 17).

There is great reliance on IT systems to develop, manufacture, maintain records, shipments, process orders, manage inventory and other critical functions. This renders their IT systems and those of 3rd party providers susceptible to disruptions and cybercrimes which could mar the company image and reputation thereby risking business operations (Case company report 2020, 21).

## 3.3 Data collection

### 3.3.1 Interviews

As one of the data collection sources for case studies, interviews allow for an in-depth case picture (Creswell & Poth 2016, 164). As a major strength of case studies, multiple data sources have been used (Yin 2003) namely interview, documentation, digital materials, media texts etc. This generally involved gathering information from participants and then classifying the information into themes which are further developed into broader patterns or generalizations compared with existing literature (Creswell 2003, 15).

For this study, open ended interview questions were drafted, discussed, and modified with contributions from supervisors to enable questions to get as much relevant information as possible and reduce influencing interviewees responses during the interview. Open ended questions allowed for the participants to discuss their opinions and thoughts more broadly without restriction. The questions were developed following the research questions and

twelve themes presented in Table 5 below. Each participant was provided with a consent form (Appendix 4) before the scheduled interview to enable them to know their rights to participation in the study.

Table 5: Operationalization of research

| Research question | Sub questions | Themes | Interview questions |
|---|---|---|---|
| How to build resilient medical equipment supply chains in industry 4.0? | How does industry 4.0 enhance the supply chain resilience phases? | Readiness | 4, 5, 6, 7 |
| | | Response | 8, 9, 10 |
| | | Recovery | 12 |
| | | Growth | 13, 14 |
| | | Digital technologies | 15, 16, 17 |
| | What strategies ensure increased resilience in medical equipment supply chains? | Resilience | 4, 5, 6, 7 |
| | | Responsiveness | 6, 7, 18, 19 |
| | | Flexibility | 9, 10, 11 |
| | | Agility | 6, 7, 22, 23, 24 |
| | | Redundancy | 9, 10, 11 |
| | | Collaboration | 6, 7, 18, 19, 20, 21 |
| | | Human Resource Management | 22 |

The pre-designed themes identified from existing literature were used to develop a total of twenty-five open-ended questions outlined in appendix 1. As stipulated by Yin (2003, 90) interviews are an essential source of case study information, hence the questions were used as a guide to the conversation rather than a query. The first three questions were background questions to enable the researcher to understand the interviewee's point of view and hence not directly linked to the identified themes. Some identified weaknesses of interviews have been linked to bias of poorly designed questions, response bias, inaccuracies due to poor recall and reflexivity whereby, the interviewee responses with the interviewer wants to hear. On the bright side, the interviews are well-tailored to the subject matter of the case study, presenting perceived causal conclusions in a thoughtful and informative manner. (Yin 2003, 87) Unlike questionnaires, interviews also allowed the researcher to ask a couple of follow-up questions to enable proper understanding or when interesting themes were discussed or mentioned.

### 3.3.2 Participant overview

Interviewees were contacted through a company contact who reviewed the interview questions and discussed the kind of participants to be recruited from the company. Interview questions were shared with the company contact taking part in the study to ease the recruitment process for the kind of participants to involve. Participants themselves were only exposed to the questions at the interview. To ensure anonymity, interview participants described in Table 6 have been assigned pseudo names. Other details include the position and duration, description of role, date of interview and duration. At this point the reader is thus acquainted with the participants to ensure accurate understanding of the various opinions and or outcomes from the interviews.

Table 6: Conducted interviews

| **Interviewee** | **Position (years)** | **Date** | **Duration** |
|---|---|---|---|
| Cand. A | Strategic Purchasing/Buyer (21 years) | 23.11.2022 | 75 minutes |
| Cand. B | Order to Remittance (3 years) more than 5 years in customer care | 24.11.2022 | 65 minutes |
| Cand. C | Global team Customer Operations (1 and half year)<br>Logistics manager (15 years) | 25.11.2022 | 55 minutes |
| Cand. D | Operations Director (19 years) | 25.11.2022 | 60 minutes |
| Cand. E | Supplier Management (10 years)<br>Global team (3yrs) | 29.11.2022 | 50 minutes |

Cand. A is a Strategic Purchasing who has worked in this role for twenty-one years for the company. According to him, "*Covid caused a delay in the supply chain…suddenly we noticed the purchasing department had a lot of things to order, much more than normally. If we ordered normally like 10 pieces, then suddenly our needs were 100 pieces*".

Cand. B has more than five years working in customer service and in her current role as Order to Remittance, she has three years of experience where she works as part of a global team. She describes her role as a "*problem solving and communication role with a pivot*

*function between commercial sales and handling products that come from other manufacturing sites*".

Cand. C is a Global Team Customer Operation who has worked as a Logistics manager for fifteen years for the company. In her current role, she has "*been leading a global team within our global customer operations called customer Operations Centre of Excellence. And what we do is that we run on a global scale of projects that are related to the customer operations.*"

Cand. D has nineteen years working with the company and has in management positions for fifteen years. As Operations Director he has been in the role for three years. He is responsible of the whole manufacturing chain, from the raw materials, whether it's the machines or software, he is responsible for getting the materials to the customers. His first thoughts on supply chain resilience are "*how robustly we can actually deliver the product to the customer? How do we source the material? How do we make sure that we have the material we need for our manufacturing? How have we ensured correct capabilities to make the products in our manufacturing?"*

Cand. E has ten years of experience as Supplier Management, and she has been a part of the global supplier management team for three years now. To her, *"a big part of resilience or flexibility on the chemistry side is having two to three different options for chemistry raw materials."*

In addition to conducted interviews, data including reports was also collected from the company website and from company presentation shared by interviewees. In order to adhere to the company's policies, only data available publicly could be used by the researcher. The main aim of this data was to understand the company as a whole, and back up the discussions with the interviewees to ensure the information provided was in sync.

## 3.4 Data analysis

Having data alone is not enough except sense can be made from it. The formulation of a case description constitutes the central component of the data analysis method. This case description will, in the future, serve as the foundation for the formulation of emergent research questions and the framework for the case study. (Eriksson & Kovalainen 2015,

Two strategies of analysis section). The analytical method used here is thematic analysis, chosen for its flexibility in choosing themes (Braun & Clarke 2006). Thematic analysis refers to "*a method for identifying, analysing and reporting patterns within data*" (Braun & Clarke 2006, 79). According to Malhotra's four stages of qualitative data analysis (Figure 6), we assembled, reduced, displayed, and verified the data (Malhotra 2017, 240). This was done following the six phases of thematic analysis (Figure 7) described by Braun & Clarke (2006, 87)

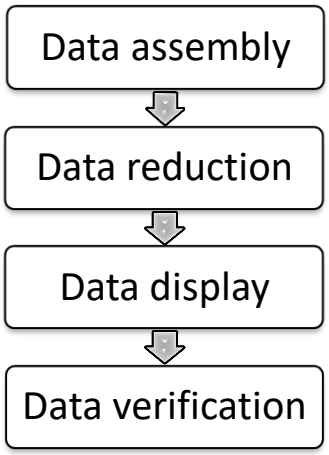


Figure 6: Stages of qualitative data analysis (Malhotra 2017, 240)

**Data assembly** involved gathering data from varying sources. This included data collected from interviews (including recordings, notes, and transcripts) and company report, web pages, and power point presentation necessary for the study. All interview transcripts were individually transferred into 5-7 pages long word documents.

**Data reduction** involved organizing and structuring the data. When transcribing the data only the useful information was included, and the rest was trimmed off. Interview audio and transcript from otter together with researcher's notes were cross checked.

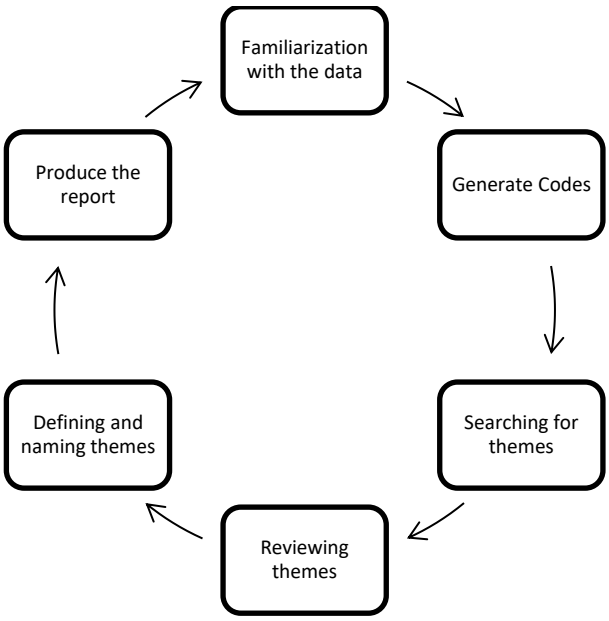


Figure 7: Phases of thematic analysis (adapted from Braun & Clarke 2006, 87)

Using Nvivo software, the transcribed documents for each interviewee were uploaded and then references used to map interviewee responses to the data themes or segments. For phase two of thematic analysis, the data was then organized into meaningful groups by identifying interesting features of the data in a process called coding (Braun & Clarke 2006; Eriksson & Kovalainen 2015, Coding section).

A total of eighteen codes including “information flow”, “sourcing materials” “increase response capacity” etc. were generated in the coding process and presented in a code book (Appendix 2) for which collected data was mapped to generate themes presented in this paper. The themes were reviewed and refined to ensure that there is a clear uniformity within them and differences between them. Considering the reiterative process of coding, the themes were checked again to ensure that they work in relation to the data set and checked for any additional or missing data omitted in the previous coding stages. Since themes are formed by the researcher to reflect the focus of the study, they can be inductively based on data or deductively developed from literature review, or a combination of both (Braun & Clarke 2006, 83).

In this study, themes presented in Table 5 were developed and hence guided the formulation of interview guide. Themes presented in the analysis were further defined and refined to bring out their essential meanings and what portion of the data they described and then finally illustrated and made arguments in relation to the research questions (Braun and Clarke 2006, 87-93).

**Data display** involved summarizing and presenting research outcomes. Research findings were presented as extended text and tables. Displaying the data implied a good connection made between the different data chunks (Malhatro 2017).

**Data verification** sought alternative explanations supported by other data sources and theories or concepts. To make valid interpretations, findings were backed up by past research and noteworthy remarks from researcher's interview notes (Malhatro 2017). The advantages and disadvantages of thematic analysis method are summarized in Table 7 below.

Table 7: Advantages & disadvantages of thematic analysis (Braun & Clarke 2006, 97)

| **Advantages** |
|---|
| 1. Flexibility across epistemologies and research questions. |
| 2. Relatively easy and quick method to learn and do. |
| 3. Accessible to researchers with little or no experience of qualitative research. |
| 4. Results are generally accessible to an educated public. |
| 5. Useful method for working within participatory research paradigm, with participants as collaborators. |
| 6. Can usefully summarize key features of a large body of data, and/or offer a 'thick description' of the data set. |
| 7. Highlight similarities and differences across the data set. |
| 8. Can generate unanticipated insights. |
| 9. Allows for social as well as psychological interpretations of data. |
| 10. Can be useful for producing qualitative analyses suited to informing policy development. |
| **Disadvantages** |
| 1. Flexibility makes it challenging to create detailed recommendations for higher phase analysis and can be potentially paralyzing for the researcher attempting to pick which components of the data to concentrate on. |
| 2. If not used inside an existing theoretical framework underpinning analytical claims made, it has limited interpretative potential beyond basic description. |
| 3. As an analytic method, theme analysis currently lacks distinction. |
| 4. Inability to maintain a sense of continuity and contradiction through any one individual account may be revealing |
| 5. The researcher is unable to make inferences about language use or the fine-grained functionality of discourse using a simple thematic analysis. |

Thematic analysis is a tool for analysing qualitative data that is not overly complicated. Nevertheless, the researcher needs to be aware of a number of obstacles and should make every effort to circumvent them. In order to conduct a thematic analysis, you must first conduct the analysis itself, as opposed to merely classifying the data into categories based on the topics on which the interview questions were asked. In addition, week analysis is produced by reporting the themes that emerge from using the data collection questions as the focus of the report. Furthermore, unconvincing analysis where wrong themes are use

or there is too much overlap or inconsistency. (Braun & Clarke 2006, 94 - 95) To avoid this, the researcher has actively engaged with the data in a detailed and self-conscious manner and going through the coding process and rereading the data several times to avoid unnecessary or false doubles.

## 3.5 Evaluation of the study

The researcher did not only end at carrying out a piece of research but also considered how readers will be convinced about the findings of the research. Following the criteria to determine trustworthiness of qualitative research by Lincoln and Guba (1985), this study adopts these four terms, namely “credibility” “transferability” “dependability” and “confirmability” (Lincoln & Guba 1985, 300).

The “credibility” criterion describes activities that render study findings and interpretation plausible. “How research findings match reality?” (Merriam 2015, 242). To fulfil the “credibility” criterion, this study used well recognized research methods and triangulation. An operationalization table was created to ensure a systematic approach to answering research questions using themes to formulate interview questions. Empirical data collection was from interviews which were recorded, and notes taken to ensure proper identification of salient factors during the interview. Research articles from similar studies were used to frame findings of current study and thus properly referenced in this report. The company and interviewees are not mentioned in this study which gives room for free expression of thoughts.

Unlike conventional research where precise statements can be made on external reliability, the “transferability” criterion for qualitative research seeks to provide ample evidence for anyone interested to judge the possibility to apply findings in a different context (Lincoln & Guba 1985, 316). Since the amount of proper evidence to be provided is undefined (Lincoln & Guba 1985), this study thus fulfilled this criterion by engaging in purposeful sampling using qualified participants from the case company and using authentic and appropriately referenced articles throughout the study. This ensures that a thick description under investigation is provided to ensure the audience properly understands it and is able to compare instances of the phenomenon with those emerging in another context. Such important information on the restriction in the type of people

who contributed the data, data collection methods used, length of data collection and period over which data was collected (Shenton 2004, 70) have been clearly mentioned.

The third criterion, "dependability" explains the fact that the study can be replicated using the same methodology presented, even if not to obtain the same results (Shenton 2004, 71). This study fulfils this criterion by reporting all processes in detail in the research design. Though this will depend on the case company considered, the procedures described in this report are such that a similar study can be carried out.

The last criterion "confirmability" describes the researcher's ability to be objective and ensure that the results are in fact the experiences and ideas of the informants void of researcher biases or preferences (Shenton 2006, 72). In fulfilling confirmability, this study acknowledged and clearly gave reasons for choosing one approach over others with its weaknesses and strengths mentioned. Also, data files for the study including interview audio recordings, transcript, and company documents shared are documented and saved. The provisions in Table 8 were made by the researcher to ensure trustworthiness of the study.

Table 8: Provisions addressing Trustworthiness of this research (modified from Lincoln & Guba 1985; Shenton 2003, 73)

| Quality criterion | Provision made by researcher |
|---|---|
| **Credibility** | Anonymity of company and research participants<br>Use of operationalization table<br>Adoption of appropriate, well recognized research methods<br>Triangulation using multiple sourced information<br>Description of background, qualification, and experience of researcher |
| **Transferability** | Sufficient background data to establish research context and detailed description of phenomenon.<br>Appropriately referenced articles.<br>Purposeful sampling including 5 participants |
| **Dependability** | Using overlapping methods<br>Detailed description of methodology to allow for reproducibility |
| **Confirmability** | Triangulation to reduce researcher bias.<br>Admission of researcher's beliefs and assumptions<br>Justification for chosen approach.<br>Admission of weaknesses in study methods and their potential effects<br>Detailed methodology |

Main provisions included triangulation, whereby the researcher used multiple sourced information including interviews, articles and referred to the notes taken during

interviews and company documents shared. Another provision was appropriate referencing of all articles used in the study. These articles have been cited in-text citations and full information given in the refence section at the end of the report. The methodology has been detailly described with justifications for each approach chosen. It is thus easy to trace the various steps employed by researcher to reproduce the current study.

Also, the issue of confidentiality has been addressed in this study. Personal identifiers such as names of participants, their e-mail addresses and company's name have been removed and given pseudo names. Although these add to the credibility of the study, it decreases transferability. It will be difficult for the research results to be transferred to another context, given that the current case study is unidentifiable.

In addition to the research trustworthiness, the researcher has also ensured that the study is compliant with the Finnish National Board on Research Integrity. In order to protect the research data, a Data Management Plan (Appendix 3) was created with DMPTuuli1. The DMPTuuli tool defined how various types of data would be collected, processed, stored, and treated after completing the research and destroyed after it becomes obsolete.

Participation in this study was free willed and participants consented to their data collection, storage and use throughout the research. Each participant therefore received a consent form before their interview to enable them to know their right to participation and withdrawal from the study. Adhering to the selection criteria, all research participants were adults capable of expressing their opinions on the research topic and did not need any guardian to consent on their behalf. A copy of the informed consent is attached in appendix 4.

The current study methodology is not without criticism, as there are some aspects that could have been improved upon. Firstly, conducting a single study limits generalizability of the results. While qualitative research often focuses on in-depth exploration of a smaller sample, it is still important to ensure that the data collected is robust and that the participants are representative of the population being studied. Secondly, employing multiple methods of data collection such as surveys, observations, in addition to interviews could give a more complete picture of the experiences and perspective of the

[1] https://www.dmptuuli.fi/

participants and increase validity of the results. Thirdly, during the online interviews, there were some sessions in which the researcher had to paraphrase the question for the participant to fully understand. This might have caused some biases in the way the researcher framed the question without getting the initial understanding of the informant. Finally, the findings might not be a true representation of the case company reality as the data was collected only once and not periodically to be able to see its evolution or the influence different times and events have on it.

# 4 FINDINGS

This chapter examines the empirical data collected for the study. It presents findings from the interviews, focusing on different themes and emerging patterns from the data. The findings are presented in an attempt to answer the two sub questions guiding the study; (i) how does industry 4.0 enhance the supply chain resilience phases? And (ii) what strategies ensure increased resilience in medical equipment supply chains? These questions are tackled through the themes that guided the formulation of the questions and then ends with a general outlook digital technologies contribute to building resilience in the case company. Then the modified framework of the study is presented and compared with the preliminary framework established at the start of the study.

## 4.1 Technology enhanced resilience phases

Based on the interview and operationalisation table, five themes have been identified in relation to how industry 4.0 enhance the supply chain resilience phases. These themes present an idea of the different measures taken to build supply chain resilience in reference to preparing the supply chain for eventual disruption, responding to supply chain disruptions, ensuring the supply chain regains its function after a disruption, improving the supply chain performance and the important role of digital technologies.

### 4.1.1 Readiness in anticipation for disruption

The purpose of this theme was centred around measures implemented to prepare the supply chain for uncertainties, information flow and real time connectivity update across the supply chain and its partners. The readiness of the supply chain is of the utmost importance, especially when compared to the response and recovery phases, which emphasises the relevance of making pre-emptive steps in order to establish a capacity for withstanding the effects of disruptive events (Chowdhury & Quaddus 2016, 721). Supply chain capability implies the ability to deliver a product based on strategic and operational supply chain process platforms like purchasing, production, and transportation. High levels of integration are required both inside the supply chain process and with other business processes because each of the sub-process (purchasing, production, and logistics) can either enable or threaten supply chain capacity. (Tolonen et al. 2017, 244) Thus, ensuring smooth flow of information and real time updates in all processes seemed

to improve the supply chain capability. Regarding supply chain readiness within the case company:

> *Information is always power. The more information received from the supply chain, the more in a better position you are to read the early signals of anything going on. When you start to see that something's about to happen, the site starts to take action immediately. We have actually built, long relationships with them [freight carriers]. So, by doing that, you also start to get inside information from the freight carrier, what they see that you don't know, what's going on in the marketplace. Providing that, you start to read the early warning signals.* (Global Team Customer Operations)

Similar to extant literature, early warning signals and other preventative measures are crucial in providing the capacity and insight to anticipate possible occurrences in the future (Pettit, Fiksel & Croxton 2010, 12). Although it is improbable that the focus company will ever have in-depth knowledge of all possible dangers, thorough monitoring ought to increase the possibility of this happening and offer early warning of actual events (Christopher & Peck 2004, 11). From a digital solutions perspective, the case company is thus able to use SAP to monitor performance of stock levels and complaints to the suppliers on quality and timing of the materials they provide (Supplier Management). The Order to Remittance had the following to say:

> *There's now a new module in SAP called TMS (transportation management system). And what it does is that it collects, not just, the tracking numbers and the waybill numbers, but it also sends back information from the carrier systems. So, you can see your shipments statuses in one report with one claim. When you run the report, you instantly start to get information on your different shipments.* (Order to Remittance)

Order to Remittance thus ensures that information flows to the correct people. It is her responsibility to understand departments' point of view and share possible disruption scenarios and outcomes with them (Order to Remittance). The case company has been able to keep open dialogue with key logistics partners and material suppliers (Operations Director). This breaks down functional units that could possibly stop the information flow which can lead to a general lack of communication as well as the practise of second guessing (Christopher & Peck 2004, 19).

Another important aspect of preparing the supply chain discussed by the informants had to do with maintaining the quality of goods and processes and ensuring compliance in all

fronts. Just like with food supply chains, a traceability system in place, ensures visibility of the new supply chain environment is ensured for component substitutions (Ali et al. 2021, 99).

> *We are classified as an IVD[2] manufacturing site our quality system requires that certain suppliers are audited.* (Strategic Purchaser)

Manufacturers have a responsibility to ensure that their products do not endanger the lives of consumers by adhering to strict standards of quality and regulatory compliance. Because of the importance of medical equipment and the damage that could result from production or distribution problems, it is crucial to establish reliable systems of tracking and tracing. (García-Villarreal, Bhamra & Schoenheit 2019, 729)

> *Registration depends on the country, and we must get permission from the regulatory authorities of that country so that we can perform the chase. We have the ISO 13485 standards here, we produce IVD products. For some materials, we do quality control testing before approving the material and all of this is stored in SAP information.* (Supplier Management)

The ability of the Case company to provide quality products on time depends on the ability of its suppliers to meet delivery and quality standards (Kanna & Tan 2002, 17). Medical equipment just like food products are very challenging when it comes to combining different components to make a single product. Careful substitution must be performed to assure the quality level and output of final product. (Ali et al. 2021, 99) For example, non-uniformity in medical equipment may impact performance, making product unfit for the market. As the Supplier Management puts it, "if something performs poorly, then we may suggest having another supplier."

Finally, the informants were unanimous on the frequency of dialogue or communication to ensure supply chain readiness. Be it through regular or unofficial meetings, the level of communication effort was dependent on the kind of supplier, namely key supplier, critical supplier, and general supplier.

Continuous monitoring of the supply chain is necessary. This will provide some level of end-to-end visibility and to be able to detect any early warning signs or disruptions. In

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[2] Invitro Diagnostics

order to keep track of the monitoring and supply chain events, a good information system must be in place in addition to a good communication strategy. These seem to go together as having only one of the factors may make the effect of the other insignificant. This corroborates with the findings of Lee, Kim and Kim (2014, 292), stipulating that interorganizational systems visibility increases supply chain performance. Improvements in information systems technology have allowed supply chain partners to collaborate closely to boost supply chain performance, provided all relevant information is shared with all supply chain partners. (Lee, Kim & Kim 2014, 292)

### 4.1.2 Response to disruptions

This theme focused on concrete examples where the case company responded to supply chain disruptions and if alternative processes and plant were in place to enhance supply chain response in the face of adversity. It is important to recall here, the case company mainly focuses on new-born screening products. All informants made it clear that the event of Covid-19 was unexpected and the most difficult disruption the supply chain had experienced so far.

Creating response capabilities is an important approach to becoming resilient. The ability to respond rapidly to changing circumstances is an obvious competitive advantage (Christopher & Peck 2004, 13). For our case company, they were able to modify operations in response to a disruption (Pettit, Fiksel & Croxton 2010, 12) by building instruments suitable for PCR Covid testing. The example of the 360-instrument built during the pandemic was common amongst the informants. This instrument had been in production for a couple of years, but its relevance during the pandemic still put some pressure on the supply chain as many were produced within a very short time.

> *I think we're shipping about 20 of these instruments per year, maybe 25. Then we jumped from 25 a year to 25 a week. So, it really stressed our supply chain. And it really disrupted what we were doing because on top of this increase, like exponential increase in demand for one product, we were still selling our other products.* (Order to Remittance)

Specifically relating to the most popular covid instrument, the Operations director said:

> *Normally we produce this 360-instrument like between 70 to 80 units per year. Then 2020, we produced 1050 units during eight months. It's a huge spike. It is 15 years normal production quality during eight months.* (Strategic Purchaser)

Bode et al. (2011) have argued that buffering and bridging are alternate coping strategies for dealing with supply chain disturbances, driven by motivation to act and the conditions under which this motivation is channelled into the response alternatives. Supply chain disruption orientation which results from within the firm has the highest effect on buffering and bridging. (Bode et al. 2011, 848, 850-51) As the informants mentioned, they were able to increase safety stock and establish information flow with supply chain partners.

> *You either need to build safety stocks or then you need to start to think ...do I even have a possibility of having another supplier?* (Global Team Customer Operations)

For some specific materials safety stocks were doubled or even tripled to ensure that there is backup stock for major raw materials in case something happens (Supplier Management, Strategic Purchasing). This is in line with what Hohenstein et al. (2015, 101) recommend: that businesses invest into buffers like safety stock to make sure the supply chain grows and improves in ways that promote performance and allow it to recover from disruptions.

According to an informant, there are delegated roles by product lines to understand supply and demand for their products and gather information coming from sales to mitigate any disruptions. To her, they are more demanding on their supply chain and the kind of information gives them an added advantage. With this information, they are getting more efficient in responding to changes in their supply and demand. (Order to Remittance) She goes to add that:

> *Covid has brought about certain working mechanisms we didn't have before for e.g., the supply and demand, that delegating to them more responsibility in handling our supply and demand and planning our product portfolio and stock levels etc. I think we are more prepared now for disruptions than we were before, and it has made us more agile in a way.* (Order to Remittance)

Unanticipated possibilities for achievement might also be brought about by disruptions, as covid gave the case company a chance to gain market share and solidify their position as leader in medical equipment manufacturer, in line with stipulation by Sheffi and Rice (2005, 45).

As the informant discuses on disruptions, it shows that there are major and minor disruptions and the company will focus its efforts on those disruptions that led to an escalation wherein a partner or customer was lost, thereby implying financial repercussions. In which case, there is a team set up to do a postmortem and strategies to improve the situation. (Order to Remittance) This highlights the importance of having a contingency plan in place to manage supply chain disruptions, as well as the need for continuous monitoring and evaluation of the supply chain processes to identify areas for improvement in accordance with Sun et al. (2018, 206).

The case company capitalizes on good and long-term relationships with their freight carriers after qualifying them, and this also gives room for getting inside information on what is happening in the marketplace. (Global Team Customer Operations) This is similar to the findings of Spieske et al. (2022, 14) who noted that medical supplies manufacturers increased their supply availability by capitalizing on long term partnerships.

As indicated by the informants, there are currently no alternative sites or processes producing the same instruments as the case company. The Operations Director however, indicated that “there are similar processes but no dual manufacturing. There is no direct readiness in any locations to make our products.” In the phase of a disruption, the supply chain will be super stressed if there are not alternatives to turn to. This will either mean a complete change of product or very slow response. Otherwise, the company will need to invest a lot in ensuring that they can withstand various types of supply chain disruptions.

### 4.1.3 Recovery of supply chain function

The recovery theme explored the strategies put in place to recover the supply chain and ensure business continuity after a disruption. The prevention of many issues caused by disruptive occurrences can be accelerated by investments in supply chain protection. On the other hand, it is not possible to totally eliminate interruption, which is why adaptation is required in order to adjust the plans, timetables, or inventory regulations that govern the supply chain in order to achieve the intended output performance. (Ivanov *et al*. 2017, 6166)

A company may be able to anticipate and prepare for a disruption, thereby mitigating its effects (Sheffi & Rice 2005, 42). In a similar manner, the case company starts to act

immediately when they see that something is about to happen (Global team Customer Operations).

As noted by Sheffi and Rice (2005, 43), getting back to normal after a disruption requires some time. Due to the magnitude of the covid-19 pandemic, the Order to Remittance quickly recalled that the supply chain has neither regained its functionality nor performance. The Strategic Purchaser concurred as he mentioned that markets are not yet recovered from covid, and. covid had almost doubled their inventory total value in the factory. He added that:

> *The purchasing department needs products and technicians' help or R&D's help for sourcing alternative components. We have a certain process for choosing alternative components. Buyers can propose alternative substitute component or material, but we cannot make the decision, we must wait for either products and technicians, R&D or products testing to make a substitute order for substitute material.* (Strategic Purchasing)

In addition, the Supplier Management mentioned that they have stock values and procurement team in search for options as they try to buy any whole stocks left and then transfer it to the manufacturing site. For a critical equipment manufacture like the case company, there is a lot of trust involved and even though vendors might have good performance, they still need to be reassessed. After that, the case company then develops its own processes to aligned with what changes and productions can be done. (Operations Director) In an attempt to return to normal operations, there is need to for the case company to appropriately manage the crisis and mobilize resources (Pettit, Fiksel & Croxton 2010, 12).

### 4.1.4 Growth of supply chain

This theme sought answers to how better performance after a disruption is ensured in for the supply chain and the biggest lessons learned about the fragility and resilience of supply chains to covid. The ultimate goal of supply chain resilience in growth (Hohenstein et al. 2015, 107). Measures are centred on the goal of achieving superior supply chain performance in comparison to the state it was in before the disruption (Spieske & Birkel 2021, 9).

> *There's constant monitoring in place. After a disruption, you need to monitor that whatever you have put in place is actually working. If it*

> *doesn't work, then of course, you need to take immediate actions.*
> (Global Team Customer Operations)

Monitoring performed after disturbances in the supply chain reveals efforts to go beyond recovery by not only getting back to a regular state but also reaching a new and enhanced position (Hohenstein et al. 2015, 96).

One of the informants had a lot to say regarding her learning experience in the pandemic era as she shared with a lot of emotion:

> *One of the biggest lessons I learned is that many things are not within our control, and we cannot be so spoiled or feel so entitled to say that why can't I get it or why can't I have it like this. I think covid has really taught people within the supply chain business that we are all in it together. Nothing seems harder than it did when it was in covid. What I think is busy and stressful now is nothing compared to what it was during covid. Covid has made us more aware of the challenges that we could face and more aware of where we need to work in terms of our supply chain and how the company wants to tackle those challenges.*
> (Order to Remittance)

This is supported by the idea that disruptions and crises can serve as a catalyst for change and improvement in supply chain management. The recognition of the challenges faced during the pandemic and the need to work on supply chain processes highlights the importance of being prepared for unexpected events. (Srinivasan et al. 2022, 40-41) Although there were lessons picked up, one of the informants had a negative view about her lesson. For her, not everything went by the book, though they managed to get 10 products which were good. Thus, from a quality point of view, it is not good to learn that they can do more and faster. (Supplier Management)

Not much was identified in the growth phase during the interviews. This might be because the pandemic is still going on and like the informants mentioned, the supply chain has not returned, not to talk of performing better than it did before the disruption. Informants also made mention of the effect of the ongoing war in Europe which companies are faced with and have started rethinking their access strategies (Global Team Customer Operations; Operations Director). This is in accord with Ivanov (2020, 9) who emphasizes the exceptional severity and simultaneous impact, the pandemic had on many supply chain tiers and geographical locations, in addition to the extraordinary duration.

### 4.1.5 Digitalising supply chains

This theme looked at questions on the impact of digital era on supply chains, role of technology and reasoning for implementing the various technologies by the case company. Some informants clearly were not in for an all-digitalised supply chain. Industry 4.0 technologies have the potential to empower businesses reduce disruption risks and keep their operations running smoothly (Zhang et al 2020, 2227). This is especially true for business that do not require a lot of manpower in their processes.

All informants recognised the important role technology plays in modern business processes, be it for communication within and outside the firm, or for production processes. The case company is said to enjoy several technological advantages which they are using, one of them being temperature which is an important element to track in their line of business where reagents are involved (Global Team Customer Operations), As she says *"technological advantages will play a role in how successful you are. There are even lockers that will tell you where exactly where the shipment is, the physical location, temperature, humidity, and all that."* (Global Team Customer Operations) She also added that the Transportation Management System (TMS) allowed access to hundreds of different carriers with almost no effort and the biggest advantage of using ERP was the fact that data could be added to the system (Global Team Customer Operations).

For the case company, SAP has been uses to monitor performance of stock levels (Supplier Management). The most important thing and what they do is any sort of tracking system from their carriers. Specifically for Order to Remittance kind of work, they use different kinds of software to get a generalised view of stock levels, backlog of orders, and specific information they might need. (Order to Remittance) She highlights that although the digital era has brought about abundance of information, there is still a gap in effectively using information to improve supply chain processes.

> *The digital era has brought about information, but it has also brought about problems because that information, if you don't understand how to interpret it, can be distorted. We expect information and answers right away, and in the digital era, our supply chain like before when there was no Internet you would have to wait for somebody to call you back or fax. That could take days but now I feel that if I'm asking my carrier where my shipment is, they should be able to track it.* (Order to Remittance)

SAP allows some good tools to see which purchase order lines are late. After placing a purchase order, a robot goes through the configurations and automatically updates the SAP schedules. The difficulty in this arises from the variation in the information in the documents on what kind of order is received and this is causing an issue. As an example, about thirty to forty order confirmations and tracking information were completed just before interview. (Strategic Purchasing)

> *I believe the only thing what will work in our case is combined AI and humans. Because documents which the robot cannot process have to be rechecked by humans. So, there is a so-called Error List created and then you'll need to check the file and make the final decision. But the meaning for using that property is to reduce the unnecessary routine tasks.* (Strategic Purchasing)

Similar to studies by Ralston and Blackhurst (2020, 5015) there was no capability loss reported. In the event of a crisis, a company's vulnerability may increase if it lost capabilities as an unintended result of implementing Industry 4.0 and smart technologies. This is because the supply chain of a company can be severely weakened if employees quickly forget the physical manifestation of an automated process, or if individuals who understand an automated process quit an organisation. (Ralston & Blackhurst 2020, 5007) Although informants acknowledged the role of digital technologies, they believed that digital solutions may not be solving all problems and on their own, do not get the work done. Just because the tool says something is supposed to happen does not guarantee it happening in the exact same way. And "*no matter how digitalized we are, there are still people working on it* [digital solution]" (Order to Remittance).

> *Of course, digitalization needs to be there to some level, but the solutions are not always straightforward so there's a significant knowledge needed to these big digital services, making the world better. So probably we need both digitalization and the human the human side of things. What I currently feel is that we are missing more from the human side than from the platform or software.* (Operations Director)

This resonated with findings by Ralston and Blackhurst (2020, 5015) where coexistence of human beings with smart technology enabled greater supply chain performance benefit. The case company has used Extranet and Oracle in the past but not anymore. They have been using SAP since 2010 (Strategic Purchasing) and there are no plans of changing it especially coupled with the challenges of using new technology in terms of cost and adaptability (Supplier Management).

> *We have been using SAP and I don't know if we have any plans to change it. It's not good. It's a lot of manual work. But I think there are much better systems in fields but it's too big, too expensive to change.* (Supplier Management)

Following Google Trends between 2019 and 2020, Zhang et al. (2020, 2225) suggest using industry 4.0 technologies to establish capabilities to prosper in a dynamic and uncertain world. For the Operations Director, although they use automation, there is still a need for automation services for repetitive transactions. This was also supported by another informant who would appreciate automation to replace the manual use of excel and numerous excel files currently handled, especially when out of the office and there is a need for someone to cover (Supplier Management). The Operations Director noted; "*We don't currently need the highest technology AI solutions; we do need wise robust automated systems*." Thus, the case company does not necessarily need over engineered digital solutions as they *"haven't gone to very robotic centred manufacturing."* (Operations Director)

## 4.2 Supply chain strategies

Here, seven themes were identified in relation to supply chain strategies. The themes looked at different measure applied to increase capability of the supply chain when faced with disruptions. The strategies applied before a disruption (ex-ante) and those applied after a disruption has occurred (ex-post).

### 4.2.1 Ex-ante strategies

Following the three themes identified to be a part of ex-ante strategies, the informants were asked questions regarding resilience, flexibility, and responsive nature of their supply chain. The different preparatory strategies namely resilience, flexibility and responsiveness employed are summarized in Table 9. During the interview, informants used resilience and flexibility interchangeably.

Table 9: Proactive strategies for resilience

| Themes | Quote from informants |
|---|---|
| **Resilience** | It is how well your supply chain can withstand any sort of disruption. We are very sensitive to disruptions in our supply chain, and I would say that for the Covid our supply chain was more resilient than it is now. (Order to Remittance) |
| | We have regular meetings with the different departments. And we also have general meetings with, for example, customer care because |

| | |
|---|---|
| | Customer Care is also at the forefront for us. So, we try to keep everybody as updated as possible. If I see that yesterday, we didn't have a problem with this one thing, but I see that it's a problem today. I will take that and inform it forward. (Order to Remittance) |
| | It is important that we are preparing for the new-borns. And if you don't provide the raw materials, they don't get tested. So, it's very important to have some kind of resiliency in our products. (Supplier Management) |
| | We can actually commit the vendor to have a dedicated stock for us. (Operations Director) |
| **Flexibility** | Primarily we have one supplier. Looking at the production process for Chemistry, whether it's reagents or instruments, you have to qualify your suppliers. You either need to build safety stocks or then you need to start to think about a possibility of having another supplier? But one thing with the safety stock is that you cannot have too much, else you will have capital tied to your inventory. (Global Team Customer Operations) |
| | Because we have different products in our portfolio. We have those products that we manufacture ourselves and then we also have OEM[3] products which we get from suppliers and sell forward to our customers. (Order to Remittance) |
| | There are multiple ways how we can secure ourselves even though we are single source, but of course, the single source materials are so that with this industry these drops and what has happened in the world has clearly increased the demand that you need to have alternatives. (Operations Director) |
| **Responsiveness** | We are in frequent contact with our suppliers. It's just the way that we have the information flowing. (Global Team Customer Operations) |
| | They [supply partners] are on speed dial! Because of my role I have a more in-depth relationship with our stakeholders and partners. I would say that not everybody within the supply chain has such an intense relationship with each other, but my role is so specific in what I do I have to have that sort of strong relationship with our stakeholders. (Order to Remittance) |

A thorough familiarity with the system that links the firm to its suppliers, the suppliers of its suppliers, and the consumers who are farther down the supply chain is crucial for improving the supply chain's resilience (Christopher & Peck 2004, 14). There is a dedicated team to understand demand and supply of company product lines. With that information customers can be informed on what it takes to complete a product versus how it used to be in the past. Being efficient in responding to changes might have taken a while, but Covid accelerated the efficient processes which the company currently has. According to the informant, this is one thing the company does in a preventive rather than a reactive way. (Order to remittance) The company is adapting to changing circumstances to remain competitive in the market. This provides insight into the company's approach

[3] Original equipment manufacturer

to managing its supply and demand. The introduction of cutting-edge technology is not always necessary to break into adjacent business niches, there are problems that can only be solved by thinking outside the box and providing customers with new alternatives (Srinivasan et al. 2022, 40).

Some challenges were identified by the informants presented in Table 10 below.

Table 10: Challenges in building resilient chains

| **Challenges** | **Category** |
|---|---|
| In all this, new situation, we've seen that, there is scarcity you know, we don't have enough, raw materials. (Global Team Customer Operations) | Raw material scarcity |
| At the same time when the world collapsed in a way, so your supply chains are not there anymore, we have to push out large block out the door, and first of all, bringing in more raw materials to be able to connect response to demand. (Global Team Customer Operations) | Meeting demand |
| Logistics wasn't working the same way it should and we were starting to go into a lockdown where people weren't able to come to the office, people want to come to manufacturing. This not only disrupted our supply chain, but also our internal way that we handled our employees, the business, the communication, because we didn't have Teams. (Order to Remittance) | Logistics |
| One of the biggest challenges is knowing what you need in order to have a resilient supply chain but not having those stakeholders who can make that happen, fully understand what is basically needed. everybody is aiming for the same goal, but I feel that sometimes they have a different route to achieve it and along the way, those parts don't merge, but again that is because each department has their own interests which is normal, natural and understandable. (Order to Remittance) | Stakeholder orientation/management |
| When COVID started to spread, and people started to get like sick leave from work. It also felt like damage to our supplier's capability to ship goods. (Strategic Purchasing) | Employee sick leave |
| Most of the disruptions are due to the fact that supplier cannot source the material early. Its delay in raw materials or electronical components or because during COVID Most of the manufacturers had shut down or factory was closed. Chinese government has been really cautious when they have COVID cases. They shut down the whole factory. And it's not just like few days it's suddenly it's two weeks or even month. So that kind of shutdowns will interrupt the normal material flow. (Strategic Purchasing) | Supplier delay due to lockdowns |
| Usually if the manufacturer for example is in Asia, they have like main storage in Europe and they can be like an importer company in Finland. And then it's then the next is us customer. So, the material chain is like quite long. So COVID has also like emptied the dealer chain and the storage is so there are there are not like normal quantity material in the market. So that's what is causing in the big scale interruptions. (Strategic Purchasing) | Reduced quantity material due to Covid |
| I think my biggest challenges is the database. I don't have the database. I have the SAP but others on how to manage the | Database |

| | |
|---|---|
| agreements and the communication I think that is my biggest challenge. (Supplier Management) | |

The above challenges seemed to be the most important roadblocks for the informants. The difficulty of having stakeholder to make things happen resonates with implementation issues illustrated by Knemeyer, Zinn and Eroglu (2009). They elaborate that personnel in charge of implementing a plan are the most important factor in mitigating supply chain risks (Knemeyer, Zinn & Eroglu 2009, 151), taking into account such intangible loss as trust (Knemeyer, Zinn & Eroglu 2009, 148). Without well thought policies, to attract and inspire the implementation team, concepts will not be translated into proactive planning processes and thus the importance to address internal issues around leadership, team building and motivation. (Knemeyer, Zinn & Eroglu 2009, 151) In addition, it is impossible to build resilient supply chains without trust in the supply chain partners. This is because there needs to be trust in place that whatever is said or done and agreed will be done on both sides the table. “If you don’t have trust and information flow, you will have a lot of challenges.” (Order to Remittance)

The ability of the supply chain to quickly change input or way of receiving input is directly correlated to the degree of flexibility in sourcing (Pettit, Fiksel & Croxton 2010, 12). While the benefits of single sourcing in terms of cost and quality management are clear, this strategy poses serious risks in terms of reliability. Although it is helpful to have a primary provider, backup options should be accessible whenever possible. If a manufacturer produces multiple items, it may be possible to single source each one separately and maintain a backup supply chain. (Christopher & Peck 2004, 15). For medical equipment industry, it is not very easy to have multiple sourcing for raw materials. This is mainly because of the stringent requirements (Global Team Customer Operations). In the past two years, there has been an increasing need to extend the current alternatives, and this has brought about new thinking after the pandemic challenged what the company thought were good mitigation plans. The idea of multiple sourcing may be a good solution, but it is not trouble free. (Operations Director).

A lot of monitoring for example stock level and tracking is done, to ensure visibility in the supply chain. Monitoring is also done for complaints to suppliers on the timing and performance of their supplies. Once complaints are detected, for major suppliers for example, then procurement or purchasing department meet regularly to discuss about the materials, availability, and pricing. (Supplier Management) These responsive measures

ensure appropriate reaction and adaptability to disruptions in order to get the recovery process underway as quickly as possible (Hohenstein et al. 2015, 107).

### 4.2.2 Ex-post strategies

Ex-post strategies looked at those actions taken during and after a disruption has occurred to try to recover the supply chain. These strategies were covered by four themes namely agility, collaboration, human resource, and redundancy. Collaboration was the most popular of all strategies.

#### *4.2.2.1 Agility*

The concept of agility may just as easily be applied to networks as it is to individual businesses and the presence of agile partners both upstream and downstream of the focus firm is critical to the success of an agile response (Christopher & Peck 2004, 18). The theme captured questions on real time connectivity update, information flow, how fast the supply chain responded to changes, and the time from design to market.

Informants agreed on the long production times for brand new technologies and equipment. A production process for a brand-new product would normally take somewhere up to a year depending on the product. With Covid however, it was like two-three months but normally if it is a new technology, it may take two or three years, but if based on the old technology may take one year (Supply Management). As an IVD site, the company needs to apply for all the regulatory processes, and this takes quite some time. Somehow during the pandemic, production was sped up in response to demand for covid testing. As the Order to Remittance informant recalls:

> *When covid happened, what we used to do within 1-4months had to be weekly just to make sure we kept up with current products, new products coming in and the rise in demand for our covid products. So, I was right in the middle of it. I think that's one of the biggest or most intensive sort of changes and accelerant in what has been happening so far.* (Order to Remittance)

It is crucial that the supply chain can react quickly to shifts in demand, whether upwards or downwards (Christopher & Peck 2004, 20). For example, in April production plan was increased from seven to one hundred and in May, hundred and fifty. In a certain period, the case purchasing to place a lot of purchase orders to suppliers and suppliers were at first really surprised and they did not fully understand what was causing it, the Strategic

Purchaser recalls. As the Operations Director rightly puts it, “we need to be agile to make alternative materials.”

#### *4.2.2.2 Collaboration*

This theme looked at how the case company related with its supply chain partners and the role these partners played. It also sought answers to questions on coordination and cooperation in the supply chain amongst partners. Christopher & Peck (2004, 17) recognize collaboration as an important construct in building resilience as it helps companies to significantly respond and recover from supply chain disruptions. Collaboration in the supply chain is made easier by the introduction of technologies and methods for exchanging information, which bring with them new activities and data that give accurate and relevant information. For proper situational awareness as well as the formulation of a response strategy if a disruption occurs, it is essential that the information be accurate, pertinent, and up to date. (Duong & Choung, 2020, 3498)

The visibility of a company's supply chain can be improved by working closely with both the company's customers and its suppliers, in addition to increasing the level of integration that occurs within the company itself (Christopher & Peck 2004, 19). Informants confirm the collaboration with supply chain partners and communication to ensure smooth information sharing. This collaboration is also within the company itself, amongst colleagues and building partnerships with logistics carriers to develop trust (Global Team Customer Operations).

> *It is very much a collective effort from all the parts of the organization to come together. Cooperation at the global level enabled us to pull through and there was a lot of team spirit[…] So if we look at our work closely with our partners and suppliers. We work closely with our service providers like in logistics, and those teams that handle those relationships. They are the ones who can say, hey, this situation is now that shipments coming from Singapore with this partner is going to cost five times more if we go with this route, or if we go with this link. And then there's a collective decision to be made.* (Global Team Customer Operations)

The value of cooperation and coordination in effective supply chain management, especially in times of uncertainty is highlighted. By working closely with suppliers and service providers, the organization can gather information about potential risks or cost

implications of different supply chain routes and make informed decisions that benefit the entire supply chain (Namdar 2018, 2344; Alicke et al. 2020, 4).

Not all informants were part of cooperation meetings, but it was still acknowledged that they happen to improve for example, the product and pricing (Supplier Management). Also, it is impossible to talk to all 300-400 suppliers daily, hence there is a need to prioritize the suppliers according to the levels namely key, critical, or general suppliers. As the informant explains, the philosophy in manufacturing is that they do not want to outsource essential parts of their product. This thus makes them seek to establish long term partnerships, with the depth of the relations depending on and varying from critical to general supplier (Operations Director) To this effect, the Operations Director adds, "*We do need key partners to work with us. By ourselves we are not able to make everything and do not want to be on the mercy of someone getting things done."* Forming partnerships is complex, demanding, and requires significant investment in terms of both financial and strategic resources. It is therefore important to carefully consider the potential benefits and drawbacks before investing into such partnerships. (Maheshwari, Kumar & Kumar 2006, 286)

The Order to Remittance and her team are responsible for the supply chain coordination. Other departments rely on her for a generalized view of the supply chain. Their input is needed quite often to ensure that the supply chain is functioning well, and this puts a lot of responsibility on what they do. She proceeded to say:

> *This organisation is made-up in a way that sales is doing their own thing, logistics is doing their own thing, manufacturing is doing their own thing, but I have to be able to coordinate everybody. I also have to be the voice of everyone.* (Order to Remittance)

This collaboration is not without challenges as sometimes Order to Remittance does not understand other departments or stakeholders are coming from, so they have to keep an open mind about the situation. With the flat hierarchical structure that exists in the company, there is no need to go through a chain of management to get answers. This sort of relationship thus provides some level of cooperation. (Order to Remittance)

Also, the availability of certain knowledge is some sort of internal threat when some of the knowledge is not maybe readily available. Losing some of the knowledge from the

case company is a risk even if not a high-level risk like an external risk. (Operations Director)

#### *4.2.2.3 Human resource management*

This theme looked at how employees are involved in ensuring supply chain performance. As the Strategic Purchasing informant explained, every new employee has a document. This new person goes through all the functions which they are tied up to and then there is a written document added to their human resources file. He mentioned that they have a training system in their intranet. He finished off with an example, “Today I have done two trainings at my laptop I have been here long if I look at the history of that there are I think between 200-300 trainings”. (Strategic Purchasing)

> *We are always up to date whenever there is a new product introduced. Logistics always has training, not just for the people working at the office, but for the whole shipping team. There are certain pieces of information we need to have, like how to start a product, handle it, transport it and if any specific information on special goods and based on that, we start to build the supply chain picture so to say. For other kinds of trainings, we try to keep track of what is in the market, what is about to happen and then we train the personnel.* (Global Team Customer Operations)

This ensures that every single worker in every unit including top management to be aware of the risks that they face and comprehend the part that they play in the operations (Cranfield University 2002, 7). The findings also corroborate with the stipulation by Khan et al. (2021, 12) on the need for businesses to devise strategies for training their workers in the most cutting-edge technology in a methodical and progressive manner to improve digitalization of supply chains.

#### *4.2.2.4 Redundancy*

This theme looked at alternative plant and processes and sourcing of material supplies. Surplus capacity and inventories are wastage, hence undesirable. Although possible "pinch points" can weaken a supply chain, adding more capacity and/or inventory to such locations can strengthen it. There is always a cost to consider when preserving a buffer "just in case," and that cost must be weighed against the likelihood and severity of a bad outcome (Christopher & Peck 2004, 16). This resonates with what the Global Team Customer Operations had to say:

> *You either need to build safety stocks or start thinking of the possibility of having another supplier. But then one thing with the safety stock is that you cannot have too much. Because then eventually you will have too much capital tied to your inventory.* (Global Team Customer Operations)

When it comes to sourcing, the Global Team Customer Operations agreed there were indeed alternative suppliers, but in most of the cases, "*we tend to use only one and there are also cases where we are very, very dependent on them for supplies when they're the only ones in the world that can supply certain products.*" According to Zeng (200, 220) flexibility, cost reduction, stability and improved communication are some benefits of single sourcing. On the downside, there is no bargaining power and any disruption on supplier side will cause major issues (Zeng 2000, 221). Dependence is not an issue especially if the buyer is highly attractive hence minimising problems created in collaborative new product development process (Schiele & Vos 2015, 144). As mentioned earlier, the process of qualifying a supplier is tedious and intense hence discourages the use of multiple suppliers. Manufacturers may benefit from well managed relationships with suppliers rather than relying solely on a single supplier. Multiple suppliers can potentially reduce dependence on a single source which can be advantages in case of any supply chain disruption like material shortage. Though multiple suppliers can increase competition managing multiple supplier relationships can be very challenging. (Maheshwar, Kumar & Kumar 2006, 286)

## 4.3 Modified framework

Relative to the preliminary framework, supply chain strategies were independent of each other there was no continuous learning process introduced in the supply chain phases. Strategies such as Agility, collaboration and human resource management are seen to apply both before and after a disruption. Another noticeable element is that of continuous learning process occurring across all supply chain phases. The modified framework of the study is presented in Figure 8 with modifications at the level of strategies, introduction of continuous learning indication of the industry 4.0 technology implemented.

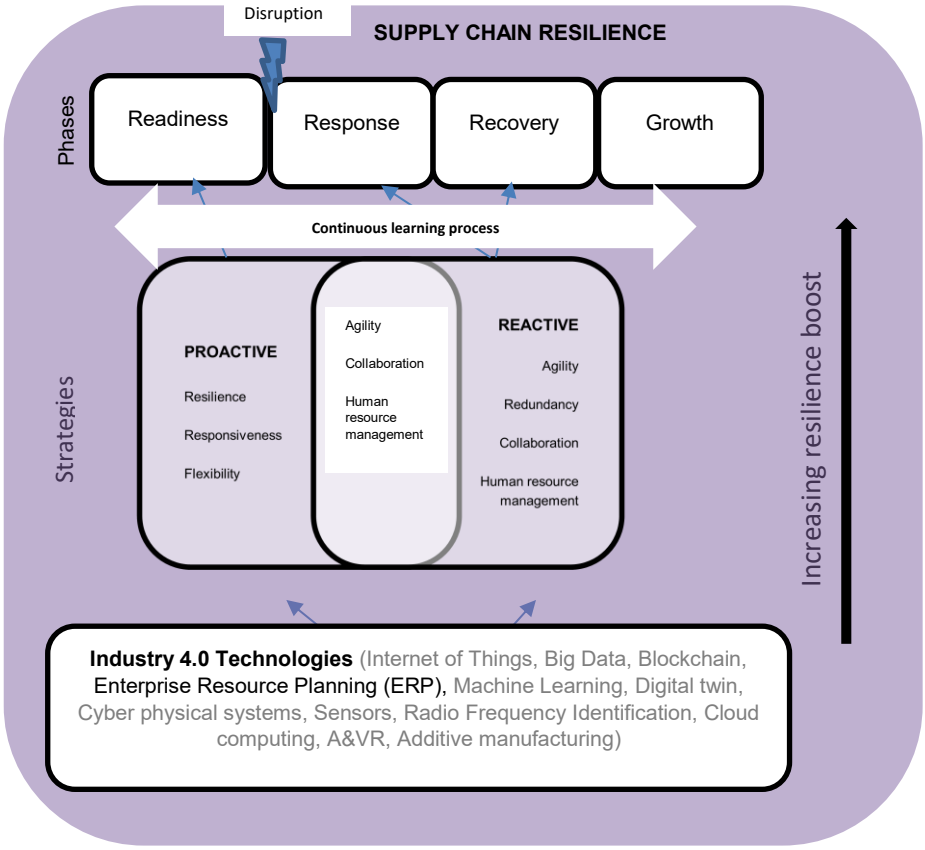


Figure 8: Modified study framework

Collaboration, human resource management and redundancy have been grouped into both proactive and reactive strategies (Hohenstein et al. 2015, 105). Managers should be aware that open communication is essential for both proactive and reactive resilience because of the good impact it has on the resilience of their teams (Wieland & Wallendburg 2012, 311).

Barratt (2004, 32) divides collaboration into vertical and horizontal collaboration as presented in Figure 9. Customers, internal departments, and external vendors can all be involved in "vertical collaboration." In a horizontal partnership, rivals work together with one other as well as with non-competitors. (Barratt 2004, 32) The link between having access to relevant information and working well as a team cannot be ignore. Collaboration can be shown in many ways, like when the top management team backs it, when it's made official, or when roles are clear. Most people agree that making a commitment to working together can help the supply chain work together better and maybe even get deeper. (Ralston, Richey & Grawe 2017, 523)

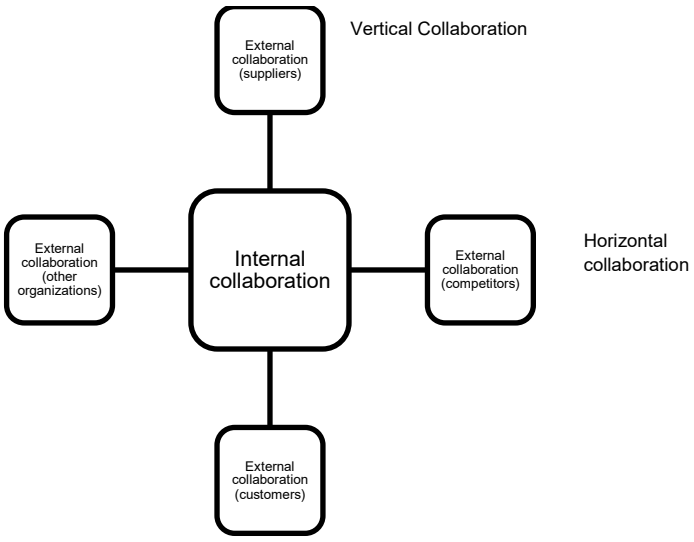


Figure 9: Types of collaboration (modified from Barratt 2004, 32)

Investing in collaboration with either competitors, suppliers, customers, institutions, or partners coming from other industries is one opportunity for acquiring options for better sensing the future (Kylaheiko & Sandstrom 2007, 980). Barratt (2004) has suggested that insufficient familiarity with the concepts of collaboration and collaboration partners contributes to many of the issues in the supply chain (Barratt 2004, 33). All partners are responsible for varying aspects of the supply chain collectively. Forecasting, product design, inventory management, and logistics are the several functions that can be used to classify supply chain collaboration according to their respective criteria. (Singh & Sachdeva 2018, 158) Study findings have indicated regular exchange of information with suppliers and also establishing partnerships with logistic carriers to facilitate trust and increase chances of competition (Global Team Customer Operations). The improved levels of transparency and collaboration that can be seen along the network of the supply chain are directly responsible for the increased levels of trust and the strengthened links that can be noticed among the participants of the supply chain (Singh & Sachdeva 2018, 161; Ghadge et al. 2020, 673).

Patruco et al. (2022) explore relevant factors on how human resources contribute to supply chain performance. Supply chain employees need to have the required level of skills and competences in order for the company to generate new information. These abilities can be improved through the employees' interactions in their professional networks, and in some instances, by the generation of new information influenced by investment in employee skills through training programs. (Patruco et al. 2022, 67) The

case company provides trainings to new recruits and even in the midst of a disruption, they were able to hire temporary workers (Strategic Purchasing). This means that these workers had to contribute to responding to the supply chain disruption and this would not be feasible if the company did not have supply chain professionals who know their suppliers fully (Global Team Customer Operations).

Continuous learning is essential in ensuring resilient supply chains. Chowdhury & Quaddus (2016) argue that continuous learning for organizations is essential for ensuring supply chain resilience. There is a need to reflect on past experiences, identify opportunities for improvement, and implement those improvements to better handle disruptions. This calls for efforts on both exploratory and exploitative learning fronts. (Chowdhury & Quaddus 2016, 711) The case company learned from the events of covid but also, they also have this continuous monitoring and tracking in place to ensure supply chain visibility. These challenges presented in Table 10 were some of the key learning points used along the different supply chain phases. The lessons from the Covid -19 pandemic should not be forgotten as the threat of the disease decreases, but it is important to make changes across the business spectrum, from executives to investors in order to build a more resilient future. This thus poses an opportunity for the company to demonstrate their purpose and prioritize building strong foundations. (Hirsh 2021, 145).

It is worth noting that, while reactive and proactive strategies can be effective on their own, a combination of both can provide the most comprehensive supply chain resilience and strategic advantage.

# 5 CONCLUSION

## 5.1 Theoretical contribution

The study sought to contribute to the industry 4.0 discussion in the medical equipment supply chain by examining how its emerging technologies can boost resilience during disruptions and prepare for future disruptions. The study has contributed to existing literature on technological solutions, supply chain resilience and the medical equipment industry.

It provides insights into how the integration of technologies such as ERP/SAP can enhance the resilience of medical equipment supply chain in industry 4.0. ERP/SAP systems provide real-time visibility into supply chain operations, enabling organizations to quickly identify and respond to potential disruptions. By integrating various functions and departments within an organization, ERP/SAP systems can facilitate collaboration and communication, enabling teams to work together more effectively to resolve supply chain disruptions. The automation of processes such as procurement, inventory management, and transportation planning through ERP/SAP systems can reduce manual errors and increase operational efficiency, improving overall supply chain resilience. ERP/SAP systems generate vast amounts of data, which can be analysed to identify patterns, trends, and potential disruptions. This enables organizations to make informed, data-driven decisions to enhance supply chain resilience.

The study also contributes to the understanding of how technologies can be leveraged to prepare for future disruptions and improve the overall performance of the medical equipment supply chains. This implies reducing inefficiencies, increasing visibility and responsiveness, and anticipating and mitigating disruptions. By understanding how technology can be leveraged, supply chain professionals can optimize processes, improve communication and collaboration, and make data-driven decisions to enhance supply chain resilience and overall performance.

A deeper understanding of the key concepts, challenges, and opportunities for building resilient medical equipment supply chains in Industry 4.0. Our findings relating to opportunities created by the pandemic are consistent with Sheffi and Rice (2005, 45) as the company was able to gain market share and position as a result of the dynamics brought about by the pandemic.

An analysis of the different phases of supply chain resilience and how they can be enhanced in the context of Industry 4.0. Monitoring was stressed to be applied throughout the supply chain phases before and after a disruption. The important role technology plays in building resilient supply chain cannot be overemphasized. Technology such as ERP/SAP is crucial in monitoring and tracking for e.g., stock levels and order backlog. Emphasis was laid on combined artificial intelligence and human activity to eliminate certain errors and jobs which the robots cannot handle. This is in accordance with findings of Ralston and Blackhurst (2020, 5015).

A framework for building resilient medical equipment supply chains in Industry 4.0, that provides a holistic approach to addressing the different phases of supply chain resilience as presented in section 4.3.

Identification of strategies that ensure increased resilience in medical equipment supply chains. The study confirmed the findings on early warning signals and monitoring in anticipating future disruptions (Christopher & Peck 2004, 11; Pettit, Fiksel & Croxton 2010, 12). Reading early warning signals through building relationships with partners allows the capability to gain inside information. Another strategy is establishing a reliable system of tracking and tracing (García-Villarreal, Bhamra & Schoenheit 2019, 729) through quality control testing, ISO 13485 standards and being classified as an IVD manufacturing site.

## 5.2 Managerial implications

From a managerial perspective, the study provides practical recommendations for building resilient medical equipment supply chains in Industry 4.0. It provides insights the importance of building diverse and flexible supplier base and the benefits of having robust contingency plans to place minimize the impact of disruptions. The findings of the study are useful for managers and decision makers in the medical equipment industry as well as supply chain actors and other industries that rely on complex and interdependent supply chains.

Implementing advanced technologies such as IoT, AI, and big data analytics to improve supply chain visibility and monitoring, and to increase the ability to respond to disruptions. There is the need to automate services for monotonous transactions without capability loss as suggested by Zhang et al. (2020, 2225). Investing in technology

solutions without necessarily replacing human effort will speed work processes and increase resilience capacity for future disruptions.

Building a diverse and flexible supplier base to reduce the impact of disruptions and increase the ability to recover quickly. Measures should be taken to reduce service dependency on other partners and ensure that the company has the capability to perform some of the services themselves.

Just as Kleindorfer and Saad (2005, 55) have argued that prevention is better than cure, high occurrence risks should be considered way in advance when designing anticipatory supply chain strategies. Strong backup plans should be put in place to lessen the blow of disruptions and get things back to normal as soon as possible.

For actors in the supply chain, overall resilience and performance can be improved by fostering supplier relationships. Building strong relationships with suppliers ensures timely delivery of critical components and materials. This also encourages collaboration among actors including suppliers, manufacturers, and distributors. Through collaboration, they are also able to diversify the supplier base to reduce the risk of disruptions and ensure steady supply of materials.

From findings suggesting independent operations of different departments within the organization, it is important for supply chain actors to work together and share information in order to achieve common goals. This can be achieved through open and clear communication channels, regular meetings, and development of shared metrics and key performance metrics that align the various departments. In addition, involving key stakeholders from each department in the decision-making process can help ensure that everyone works towards the same end goal.

## 5.3 Limitations and future research suggestions

Although this study presents theoretical and managerial contributions, it also presents some limitations which are outlets for future research. First, the findings may not be generalizable to other industries or contexts, as the research is focused on the specific case of building resilient medical equipment supply chains in Industry 4.0. The research is based on a single case study, which limits the ability to make inferences about the broader population of medical equipment supply chains in Industry 4.0.

The research may be affected by potential biases, such as self-reported data, which can lead to inaccurate or incomplete information. The research may not be able to capture the full complexity of the real-world challenges and opportunities of building resilient medical equipment supply chains in Industry 4.0.

In terms of future research, several directions could be taken to build on the findings of this study. Conducting further case studies on different types of medical equipment supply chains in Industry 4.0, to gain a more comprehensive understanding of the challenges and opportunities for building resilient supply chains in this context. A comparative study on different countries medical equipment supply chains to understand the differences and similarities in terms of the challenges and opportunities for building resilient supply chains in Industry 4.0 is thus encouraged.

Since the present study was a cross sectional collecting data just once at a given period, conducting a longitudinal study to understand how resilient medical equipment supply chains are evolving over time in Industry 4.0 is thus relevant.

# 6 Summary

Supply chain resilience needs to possess the ability to anticipate, respond, recover, and grow from disruption events. The introduction of Industry 4.0 has brought about a significant shift in the way supply chains are managed and operated. With the integration of advanced technologies, supply chains have become more complex, dynamic, and interconnected. However, this increased complexity also increases the potential for disruptions and vulnerabilities. The medical equipment industry is particularly vulnerable to supply chain disruptions, as medical equipment is critical for the delivery of healthcare services and any disruptions can have severe consequences on patients' lives. Therefore, it is crucial for the medical equipment industry to develop resilient supply chains that can withstand disruptions and continue to function effectively. Emerging technologies thus have a role in increasing resilience during disruption, as well as prepare the supply chain in anticipation for future events. Though companies have shown interest in using smart technologies and processes, the rate at which they invest into these technologies vary with respect to company priorities. This thesis aimed to explore how resilient medical equipment supply chains are built in industry 4.0. The sub questions were to investigate how industry 4.0 enhance the supply chain resilience phases and what strategies ensure resilience in medical supply chains. The initial framework constructed from extant literature covered resilience phases, strategies and industry 4.0 technologies.

Empirical data was collected through a qualitative study using open ended questions built from the theoretical framework. Using a single case study, five informants were interviewed, all with extensive supply chain experience. All interviews were recorded and to enable detailed transcription and coding. The data was analysed using themes presented in the operationalisation table and others emerging from the interviews.

The research contributes to theory by providing a framework for building resilient medical equipment supply chains in industry 4.0. This framework incorporates a phased approach to enhancing the resilience of medical equipment supply chains and provides a structured approach for addressing the different phases of supply chain resilience. It also contributes to the understanding of how these technologies can be leveraged to prepare for improve supply chain performance and prepare for unplanned disruptions by providing greater visibility, improving collaboration and streamlining processes. Results also reveal the interdependency of strategies to achieve resilience. It concludes that

strategies such as continuous monitoring and tracking, collaboration, and human resources are most important for building resilience in medical equipment industry.

The study results are beneficial for supply chain managers, supply chain actors and decision makers in the medical equipment industry as well as other industries that rely on complex and interdependent supply chains.

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# APPENDICES

## Appendix 1 Interview guide

1. Kindly introduce yourself telling us briefly about your background.
2. How long you have been in your current position?
3. What does supply chain resilience mean to you? How is it perceived by your company?
4. What activities are implemented to prepare the supply chain for uncertainties and disruptions?
5. What early-warning systems do you have in place to monitor potential risks and disruptions?
6. How does information flow among supply chain partners?
7. How do you ensure real-time connectivity update?
8. Could you tell me instances where your organization responded to supply chain disruptions?
9. Are there other plants capable of producing the same products?
10. Are there any alternatives process plans?
11. Do you use multiple or single sourcing for your supplies? Why?
12. What strategies are put in place to recover the supply chain after a disruption?
13. How do you ensure that the supply chain performs better after a disruption, than it did before the disruption?
14. What is the biggest lesson learnt during and after the covid pandemic on the resilience and fragility of supply chains?
15. How has the digital era impacted the supply chain?
16. What is the role of technology in enhancing the supply chain?
17. Which technologies are implemented and why?
18. What is the role of supply chain stakeholders/partners?
19. What type of relationship do you have with supply chain stakeholders/partners?
20. How do you coordinate the supply chain with stakeholders/partners?
21. How do you cooperate with supply chain partners?
22. How are employees involved in ensuring a performant supply chain?
23. How quickly can a new product be designed, produced, and distributed?
24. How fast can the supply chain respond to supply and demand changes?
25. What challenges have you encountered building resilient supply chains?

## Appendix 2: Interview code book before theme generation

| Name | Description | Files | References |
|---|---|---|---|
| Need to be agile to make alternative materials | knowledge of SC operations, environment, and status | 5 | 22 |
| Challenges | difficulties encountered | 4 | 13 |
| Cooperating with others | working together for mutual benefit | 5 | 51 |
| Information flow | circulating information within the SC | 5 | 29 |
| Digitalization | digital solutions | 5 | 35 |
| Disruption | events that interrupt normal SC function | 5 | 11 |
| Sourcing materials | ability to quickly react and respond to disruptions | 5 | 34 |
| Improvements in the SC | supply chain performing better than before the disruption | 4 | 10 |
| Lesson learned | learning from experience | 1 | 4 |
| Employee involvement | employee engagement | 4 | 9 |
| Preparations for disruptions | what is done before a disruption happens | 5 | 27 |
| Business continuity | getting the SC to function again | 5 | 11 |
| increase response capacity | additional capacity employed during a disruption | 5 | 33 |
| Regulations | laws governing processes/procedures | 3 | 13 |
| Resilience | different ways/tools used to help SC adapt to changes | 4 | 30 |
| response to disruption | actions in response to a disruption | 5 | 20 |
| sensitivity to disruption | making organization more sensitive to react rapidly by proactive info sharing | 4 | 14 |
| time factor | timely manner of things | 5 | 10 |

# Appendix 3 Data management plan (DMP)

## Building resilient supply chains in industry 4.0: The case of medical equipment industry

### Research data

**List of research data:**

| Research data type | Contains personal details/information* | I will gather/produce the data myself | Someone else has gathered/produced the data | Other notes |
|---|---|---|---|---|
| Interviews (Recorded voice/video lasting 60-90 minutes per participant which are transcribed into text for analysis) | X | X | | |
| Published Reports, and articles on supply chain resilience. These data are usually presented in form of text, and graphics in pdf, doc, and ppt format | | | X | |

### Processing personal data in research

**Does your data contain personal data?**

- My data does not contain personal data

Personal data collected include names, roles, duration in the role, and place of work of participant (s). The purpose of these data is to understand possible factors that influence perceptions of supply chain resilience.

**Who is the data controller?**

- Student

I am responsible for controlling any collected data related to this research.

### Permissions and rights related to the use of data

**Who has collected the data you use in your research?**

- I use data which is collected by someone else
- I have collected the data

Data collected by me is not shared with any third parties. Data published in the thesis report which is accessible to the public does not contain personal data identifiers. Permissions and rights relating to the use of interview data are sought from research participants using informed consent and data protection notice.

**If you use data that you have collected by yourself you may need separate permissions to use the data you collect or produce, both in research and in publishing the results. If you are archiving your data, remember to ask the research participants for the necessary permissions for archiving and further use of the data. Also, find out if the repository/archive you have selected requires written permissions from the participants.**

| Research data type | Acquired via | Permission from participants |
|---|---|---|
| Interviews | Internet-assisted software (Zoom and Otter) or face-to-face meeting | Yes |
| Reports, articles, company texts | Internet search | No |

**If you use data that someone else has collected: do you have the necessary permissions to use the data in your research and to publish the results? Are there copyright or licencing issues involved in the use of the data? Note, for example, that you may need permission to use the images or graphs you have found in publications.**

Reports: For any reports with copyright or licensing issues, I will comply with the copyright and permission requirements.

### Storing the data during the research process

**Where will you store your data during the research process?**

- In the university-provided Seafile Cloud Service
- In the university's network drive

Most of the collected data are stored in the university's network drive and Seafile Cloud Service. For data analysis, data are converted to text using Otter's cloud service and Nvivo software. These programs are authorized to be used in research and comply with GDPR requirements.

**If you don't use University's data storage services tell, where are you going to store your data and specify how you will ensure data security and file backups?**

In addition to the University's data storage services, collected data will be stored on my personal computer (Lenovo laptop). My computer is regularly updated with the latest antivirus software to ensure security.

## Documenting the data and metadata

**Can you describe what has happened to your research data during the research process? Data documentation is essential when you try to track any changes made to the data.**

- To document the data, I will use A readme file linked to the data that describes the main points of the data
- To document the data, I will use A separate document where I will record the main points of the data, such as changes made, phases of analysis, and significance of variables
- To document the data, I will use A field/research journal

**If you don't use any of the above mentioned, describe, how you document your research process?**

Question not answered.

**How will you keep your data in order and intact, as well as prevent any accidental changes to it?**

- I will keep the original data files separate from the data I am using in the research process, so that I can always revert back to the original, if need be
- Version control: I will plan before starting the research how I will name the different data versions and I will adhere to the plan consistently

**Metadata is a description of you research data. Based on metadata someone unfamiliar with your data will understand what it consists of. Metadata should include, among others, the file name, location, file size, and information about the producer of the data. Will you require metadata?**

## Data after completing the research

**What happens to your research data, when the research is completed?**

Data collected will be stored for a maximum of 5 years according to the university recommendations.
I will destroy personal data immediately because it will not be necessary to keep it longer than required.

**If you will store the data, please identify where and for how long?**

I will store all data on my laptop including personal data for max. 6 months until the research has been approved.
Data in the university shared drive will be stored for max 5 years.

## Appendix 4 Consent form



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**Concerns:** Consent for the Collection, Storage and Use of Data
**Research Topic:** Building resilient supply chains in Industry 4.0: The case of medical equipment company
**Responsible researcher:** Elizabeth Wirsiy

Turku School of Economics, University of Turku, Finland

Dear Research Participant,

Thank you for your interest in the details pertaining to this research and the subsequent interview that you are participating in as part of the research.

**Collection and Use of Data:** The data you are providing serves several purposes, which include:

(1) The researcher will use data from the interviews for further processing/ analysis to gain understanding of how resilient medical supply chains are built in Industry 4.0.

(2) The insights gained from the analysis are primarily used for the master's thesis. Step one in processing of data is the anonymization of all data. After this step is completed, no individual information can be traced back directly to any individuals.

**Storage of Data:**

(1) Storage during data collection: during the collection of data, comprising of interview(s), data is stored by the researcher. Data is stored securely in the university provided Seafile Cloud Service and in the university's network drive and transcribed into texts using authorized research software. Specific data retrieval for the collected data is only directly accessible by the researcher.



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University of Turku | School of Economics
FI-20014 University of Turku, Finland
Telephone +358 29 450 5000

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(2) Storage after data collection: upon collection and during the analysis stage, data is extracted in anonymized form and stored in various formats to suit the analysis. All formats of data are stored securely in the university provided locations, and only the researcher has access to the data storage.

(3) Duration of data storage: the data collected is stored maximum 5 years upon collection to serve the analysis and reporting of the master's thesis. Data will be securely destroyed after this date.

**Consent acknowledgement:**

By receiving this informed consent and participating in the interview, you authorize the collection, processing of any personal data in compliance with the EU General Data Protection Regulation and the Finnish Data Protection Act (1050/2018). You can revoke your consent with effect for the future.

**Withdrawal at a later stage:**

Each participant can demand the exclusion of own data for further use beyond the purpose(s) of the thesis you are participating in. This is possible regardless of whether you have granted permission to use your data at the onset of data collection. If you choose to withdraw from your data to be used for or after the thesis, please send an email with this request to welmus@utu.fi by the 31st of December 2022 at the latest. After that date, data will be anonymized, and the researcher will be unable to identify your individual responses.

The collection, storage and use of data is in line with the ethics recommendation at the University of Turku, Finland.

Privacy Notice https://www.utu.fi/en/privacy/notice

Data Security description of University of Turku

https://www.utu.fi/en/privacy/data-security-description

If you have further questions, please don't hesitate to contact welmus@utu.fi.