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Assessing supply chain resilience capabilities among manufacturing firms: a closer look on supply chain flexibility

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Submitted by:
Jansen, Wolf
S1136922

Supervisors University of Twente
1st: Dr. Ir. Petra Hoffman
2nd: Msc Esmee Peters

Practical Supervisor:
Evofenedex - Msc Nanne Schriek

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As a writer, I wish you enjoy this reading!

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Wolf Jansen

Abstract

Motive: Supply chains are increasingly becoming more vulnerable to disruptions. Traditionally, risk management approaches are used to assess possibilities of disruptions. However, this approach is deemed as outdated, as often the rare or unpredictable disruptive events do most damage to supply chains. To address this challenge, the concept of supply chain resilience has emerged as a more effective methodology for preparing supply chains to withstand and recover from unforeseen events. Despite its growing importance, empirical research in the field of supply chain resilience remains limited, making it difficult for practitioners to justify investments in resilience measures, as: '*nobody gets credit for fixing problems that never happened'.*

Purpose: Therefore, this study aims to explore and provide empirical insights into the different capabilities of supply chain resilience, specifically identifying strategies for organizations in the process and manufacturing industry to increase supply chain resilience in areas where they are most lacking.

Method: To address this, a mixed methods approach was utilized. Initially supply chain resilience capabilities were systematically analyzed across 85 manufacturing firms, revealing that supply chain flexibility was the lowest scoring capability. To further explore this area, world café discussions were conducted with supply chain managers to identify methods and difficulties in enhancing supply chain flexibility. These difficulties were then further examined through expert interviews, where difficulties identified in the world café sessions were discussed, and potential solutions were proposed.

Findings: This research reveals that organizations face significant challenges with organizing supply chain flexibility, which contributes in fostering supply chain resilience. A major difficulty identified is the ability to easily modify processes and the sequence or route of production operations. This was also evident within the qualitative part of this study, as product complexity emerged as a major constraint in building supply chain flexibility. To enable flexibility and limit product complexity, optimizing product design, and more specifically introducing product modularity was found as the most striking method for enhancing overall supply chain flexibility.

Practical implications: A key strategy identified for organizations aiming to enhance their supply chain resilience is to focus on improving supply chain flexibility through better product design, particularly by implementing product modularity. Altough the qualitative results of this research may be context-specific, the insights gained provide valuable guidance for firms in the process and manufacturing industry to consider. By adopting product modularity, organizations can take a proactive approach to building a more resilient supply chain.

Keywords

Supply chain resilience, supply chain resilience capabilities, supply chain flexibility, flexibility

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List of abbreviations

Acronym	Definition
SCRM	Supply Chain Risk Management
SCRES	Supply Chain Resilience
SCF	Supply Chain Flexibility
WC	World Café
MTO	Make-to-order

1. Introduction

In recent times, companies operating in the manufacturing industry have faced substantial supply chain disruptions. These disruptions, attributed to events such as the COVID-19 pandemic, the Suez Canal blockade, and the ongoing Russo-Ukrainian war, have significantly impacted supply chain operations of these organizations. (Dyson et al., 2023; Fan et al., 2022, p. 1; Ivanov, 2020, p. 2). These seemingly low-frequency–high-impact events are noticeably occurring more often, resulting in an increase of disruptions in supply chains (Cao et al., 2022, p. 2; Modgil et al., 2022, p. 1247). Trends in operations considering outsourcing, globalization, reduction of the supplier base, reduced buffers, increased demand for on-time deliveries and shorter product life cycles results in enhanced supply chain complexity, making disruptions more fatal when happening (Wiedmer et al., 2021, p. 336). However, most organizations were unprepared to ensure supply chain resilience (SCRES) to combat disruptions in supply chains (IMS, 2021, pp. 3, 6). In the fourth-round survey of the Institute of Supply Management on the impact of COVID-19 on supply chains, among the companies surveyed, 97% suffered supply chain disruptions. Notably, 47% in the United States, 53% in China, and 55% in Japan lacked effective plans for coping with these disruptions, indicating a significant gap in preparedness despite being aware of potential risks (IMS, 2021, pp. 3, 6)."

Given that around 20 percent of supply chain disruptions result in financial losses exceeding $500 million and could potentially lead to an average decrease of 25 percent in share prices (Conrad, 2013), it suggests that companies facing such disruptions are prone to enduring significant long-term impacts on their financial performance. (Sun et al., 2012, p. 59). Therefore, it is crucial to prioritize building resilient supply chains. This approach allows managers to gain a better understanding of risks and improve the firm's flexibility. (Lin & Zhou, 2011, p. 163). From the standpoint of a supply chain manager, justifying investments in SCRES strategies can be challenging (Tukamuhabwa et al., 2015, p. 12). Today's supply chains primarily prioritize cost efficiency, and the benefits of investments in SCRES capabilities are typically only realized in the event of a disruption, from which the occurrence and effect are often unknown (Rajagopal et al., 2017, p. 674) This results in problems often stemming from funding constraints, as *"nobody gets credit for fixing problems that never happened"* (Repenning & Sterman, 2001, p. 64). Exploring and looking for proven SCRES strategies diminishes this challenge, as it counters the reasoning behind the reluctance to invest. To promote SCRES effectively, it becomes imperative to investigate the relationship between

SCRES capabilities, strategies, and their potential impact on business performance (Colicchia & Strozzi, 2012, p. 414).

Constructing a resilient enterprise commences with building capabilities prior to a disruption, to be able to anticipate on changing environments. This enables further capabilities to adapt, respond, recover and learn from disruption (Ali et al., 2017, p. 28). Therefore, the ability to anticipate on disruptions enables the ability of an enterprise to be resilient. Focusing on the ability to anticipate also enables the holistic sense of resilience, in which the focus should be on anticipating and adapting to changing environments, and not solely the focus on overcoming and getting back to a 'normal' state (Wieland & Durach, 2021, pp. 317-320). This proactive perspective of resilience has been adapted in more recent literature, parallel with the increasing interest in the complexity of the modern world in the era of VUCA (Gao et al., 2021, pp. 465-470). Ultimately, this leads to a segregation in resilience strategies as described by Wieland and Durach (2021, pp. 317-320), in which engineering resilience and social-ecological resilience are described. Engineering resilience refers to the perspective of the supply chain as an engineerable system, in which state of the system is static, and where potential deviations must be diminished to return to an equilibrium as fast as possible. Social ecological resilience mentions the supply chain as a complex adaptive system, in which non-linearity, uncertainty, thresholds, and surprise are emphasized. It is the task of social actors within this system to guide the transformation towards a desirable trajectory. Combining this view with SCRES, social-ecological resilience is attained by focusing on anticipating and adapting, in which anticipating serves as a foundation for being able to adapt.

Anticipating on disruptions is done by identifying the potential, which is accomplished by focusing on situational awareness, robustness, and knowledge management. The first step in creating a resilient enterprise is focusing on situational awareness (Ali et al., 2017, p. 25). Situational awareness involves an understanding of supply chain capabilities, to be able to assess vulnerabilities in resilience, and planning for possible disruptions (Priya Datta et al., 2007, pp. 188-189; Vargo & Seville, 2011, p. 5261). Assessing SCRES capabilities has been a topic of interest in SCRES research, where early research focuses on the engineerable perspective of resilience by measuring time-to-recovery, time-to-survive and the trajectory of recovery after a disruption (Simchi-Levi et al., 2014, pp. 99-101; Simchi-levi et al., 2018, pp. 1-33; Tierney & Bruneau, 2007, pp. 14-18). Pettit et al. (2013, pp. 46-73) was the first to adapt a proactive sense in assessing SCRES capabilities, by developing a self-assessment for organizations to assess their individual SCRES capabilities and vulnerabilities, striving to reach a zone of balanced resilience.

Evaluating these measurements through the lens of social-ecological resilience by Wieland and Durach (2021) reveals a certain literature gap within SCRES assessments. Pettit et al. (2013) addresses proactively measuring SCRES capabilities, but fails to take a multi-tier supply chain view in account, undermining the complexity of supply chains that is included in a social-ecological view on resilience (Choi et al., 2001; Wieland & Durach, 2021). In an evaluation of this SCRES assessment model, Pettit et al. (2019) denotes that a firm's resilience is clearly affected by its up- and downstream partners ability to anticipate and responds to disruptions. Therefore, an assessment of only the focal firm does not comprise the true resilience of an enterprise, and there is a need for a multi-tier SCRES capability assessment. This gap in research was also noticed by Wieland and Durach (2018) in their call for papers for a special topic forum on participating in the wider debate on resilience. It is argued that to prevent resilience from becoming another buzzword, papers should provide true "SCM perspectives" on resilience. Meaning: "papers should explicitly address multiple supply chain actors, as resilience to supply chain events is commonly the outcome of interactions amongst multiple actors in the network" (Wieland & Durach, 2018). A recently developed SCRES assessment tool by the consortium Next Gen Resilience (NGR), aims to cover the mentioned literature gaps, and offers an opportunity for evaluation to supply chain managers to gain more insights in focal, as well as up- and downstream SCRES capabilities. This tool captivates the multi-tier nature of supply chains, as well as the holistic sense in measuring SCRES capabilities in pre-disruptive state.

Utilizing the NGR assessment tool, and responding to calls of Wieland and Durach (2021), and the defined literature gap, this research proactively assesses SCRES capabilities for different organizations on a multi-tier level. By doing so, resilience levels are evaluated among companies, opening an opportunity to improve total SCRES levels, as fostering the ability to anticipate facilitates the path to further resilient practices (Ali et al., 2017). The results of the NGR scan concluded that the mean of the SCRES capability flexibility was scored the lowest and was the only capability where the mean was significantly different to all other capabilities, suggesting an area of interest. Looking at available literature, many address the importance of adaptation and reconfiguration mechanisms enabled by flexibility to enhance SCRES (Ali et al., 2017; Brusset & Teller, 2017; Piprani et al., 2022; Tukamuhabwa et al., 2015). But few studies focus on difficulties in building flexibility to foster SCRES, and how to overcome these. To transition the topic of SCRES from conceptual to empirical studies, insights from practitioners are essential (Ali et al., 2017). Furthermore, this approach

overcomes the reluctance to invest, which is experienced by managers regarding SCRES (Colicchia & Strozzi, 2012, p. 414).

This research takes a holistic view in SCRES assessment as described in a social-engineering sense by Wieland and Durach (2021), focusing on extending its application in practice beyond the boundaries of a single firm, by also taking up and downstream partners in account (Ambulkar et al., 2015, pp. 119-120). This research is also in line with contemporary calls to transplant ecological thinking into management disciplines, it is imperative for supply chain managers to develop resilience in the social-ecological sense (Ergene et al., 2021, p. 5), as it equips them with the essential capability to navigate the nonlinear, uncertain, and frequently unpredictable dynamics of the supply chain (Wieland & Durach, 2021, p. 320). Central to these theories is the ability to anticipate on disruptions, in which the results of the NGR scan shows a certain weakness in the ability of supply chains to promote flexibility. Following these rationales, the following research question emerges to explore why organizations have difficulties with building flexibility, which is essential for anticipating on disruptions, and fostering social ecological SCRES:

"What strategies can organizations implement to overcome the biggest difficulties in building supply chain resilience capabilities?"

To answer the central research question, the following sub-questions have been formulated:

1. *What supply chain resilience capabilities are described?*
2. *How are supply chain resilience capabilities evaluated?*
3. *What are the outcomes of these evaluations among organizations in the process and manufacturing industry?*

The second sub-question revealed that the capability supply chain flexibility (SCF) was noted as a significant challenge. Therefore, the scope of the following sub-questions revolves around SCF.

4. *What dimensions of supply chain flexibility are recognized?*
5. *What difficulties in building supply chain flexibility are experienced by practitioners?*
6. *How do organizations overcome difficulties in building supply chain flexibility?*

This study utilizes a mixed methods approach to answer the central research question. Firstly, a survey methodology is used to assess SCRES capability levels among manufacturing firms. Following, methodologies to build SCF and the difficulties that are associated with this are examined using a research world café (WC) set-up. Finally, expert interviews are conducted to

see how organizations overcome challenges in building SCF. This paper contributes to theory by assessing SCRES capabilities for 85 manufacturing firms, and addressing difficulties in building flexibility, and how organizations can overcome these. Organizational data of multiple firms is difficult to gather and is thus an important addition to the domain of SCRES, which is still in development. Further theoretical contributions can be found in adding empirical data to the body of SCRES, which also holds close value to the practical contributions, which include different methodologies that enhance SCF. This research helps organizations get a better understanding of SCF and the opportunities for their specific case.

The outline of this paper is as follows: Chapter 2 provides a review of existing literature on SCRES and SCF pinning the theoretical base and contextual background for this study. Chapter 3 provides the research methodology utilized to address the research question, consisting of a detailed explanation of the research design, data collection methods, sampling techniques, and the analytical approaches that are used. Chapter 4 presents and critically analyzes the results obtained from the research, presenting insights into the findings. Finally, Chapter 5 concludes the paper by summarizing the key findings, discussing the implications for theory and practice, addressing the limitations of the study, and proposing directions for future research.

2. Literature review

This conceptual foundation will help understand the literature and guide the direction of this research, and will address the first and third sub-question of this research:

- *What supply chain resilience capabilities are described?*
- *What dimensions of supply chain flexibility are recognized?*

2.1 Supply chain resilience

SCRES is a concept which holds close value to SCRM and contains elements which are also seen in SCRM. Therefore, both will be addressed in this subchapter. Managing disruptions within supply chains has become a priority for researchers and practitioners, which can be accounted to two reasonings according to Pham et al. (2023, p. 219). Supply chain disruptions, defined as: "unplanned and unexpected events that interrupt the flow of materials and products within a supply chain" (Hendricks & Singhal, 2005, p. 36), have noticeably been occurring more often (Cao et al., 2022, p. 2; Modgil et al., 2022, p. 1247). Furthermore, the rise in outsourcing, globalization, reduction of supplier numbers, smaller buffers, increased demand for punctual deliveries, and shorter product life cycles enhances supply chain complexity, leading to disruptions become more critical when they occur (Wiedmer et al., 2021, p. 336). Initially, a risk management approach was conceptualized to prepare organizations for overcoming supply chain disruptions. Managing supply chain risks can be defined as "the management of supply chain risks through collaboration among supply chain partners so as to ensure profitability and continuity" (Tang, 2006, p. 453). Within this definition, the key approach intended is to signal supply chain disruption and limit impact by improving supply chain coordination or collaboration.

Transferring such static risk-management approach from an organization to a supply chain neglects the complexity aspect that supply chain bears. The thought of a complete list of risks for supply chains is misleading, and any attempt results in an incomplete list that fails to capture the intricacies of a supply chain (Wieland & Durach, 2021, p. 315). Adding to this, it is often the "black swan" events that cause the most disruption in supply chains. These are events that have not been on a list of risk sources because they were not signaled (Akkermans & Van Wassenhove, 2018, pp. 64-65). In conclusion, the traditional risk-management methods effective for individual organizations cannot be completely scaled to manage the complexities of a supply chain (Wieland & Durach, 2021, p. 315). To cover this gap, an extension of the idea of supply chain risk management (SCRM) is necessary. This can be found in the concept of SCRES, which focuses on the capability of a supply chain adapt to new environments,

disregarding the magnitude of the disruption. The relationship between SCRM and SCRES has been explored in the literature, with several studies providing empirical support for this connection. Jüttner (2011) found a positive relationship between risk-avoidant measures and SCRES. This finding was further validated by a study done by (Chowdhury et al., 2019, p. 660), which examined the antecedents and measurement dimensions of SCRES, with a SCRM culture mediating the relationship between supply chain orientation and SCRES. Additionally, (Jain et al., 2017, p. 6779) found that having a culture of SCRM contributes to overall higher SCRES levels. These studies address the relation between the concepts, and further validates the statement that SCRES is an extension of SCRM (Fiksel, 2015).

Supply chain researchers explored the concept of resilience, with early definitions centering on the ability to react and restore normal operations (Rice & Caniato, 2003, p. 24). Whilst this definition captivates essence of resilience, it still contains a certain static view by solely mentioning the outcome of a successful SCRES strategy on a singular system. Early definitions as described by Holcomb (2009, p 131) mention: *"the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function".* This definition successfully addresses the context of supply chains within the definition of SCRES. However, this interpretation uses 'desired level' in its description, suggesting a preferred equilibrium and not fulfilling the holistic sense of SCRES. Over time, the emphasis in defining SCRES shifted from ability to respond and recover to include elements of resilience-preparation and growth (Ali et al., 2017, p. 22).

The shift in perspective of resilience was also recognized by Wieland and Durach (2021, pp. 315-320). In this paper they analyzed two different viewpoints on SCRES, including an engineering approach and a social-ecological perspective. Engineering resilience finds its roots in early SCM research, where the unit of analysis is focal firm, participating in a supply chain system. Engineering resilience focuses on stability of the supply chain, aiming for little deviations from the near-equilibrium state. Metrics as time-to-recovery (TTR) and time-to-survive (TTS) were introduced within this line of thinking to distinct successful and non-successful SCRES strategies. These measures quantify the efficiency of SCRES strategies assuming a single optimal state of the supply chain. This view on SCRES is the most rigid one, but may overlook the complexities of the supply chain, especially in the face of larger crisis or changing external conditions.

Social-ecological resilience finds its roots in a need for a different viewpoint on resilience in the field of ecology. Ecological resilience is defined as "amount of disturbance

that can be sustained before a change in system control and structure occurs" and "focuses on persistence, change, and unpredictability—all attributes embraced and celebrated by biologists with an evolutionary perspective and by those who search for safe-fail designs" (Holling, 1996, p. 33). This definition does not insist an equilibrium state but accepts that disturbances can affect systems to adapt to new environments (Folke, 2006, p. 253) However this view of Holling (1996, p. 33) successfully captivates that an ecological system require ecological resilience, it is not directly transferrable to the characteristics of a supply chain. This can be accounted to the fact that supply chains also contain social actors, where ecological systems mainly focus on a system of nature. A midway can be found in the definition of a social-ecological system as described by Berkes et al. (2000, p. 10): "A social ecological system is complex, non-linear, and self-organizing, permeated by uncertainty and discontinuities". A social-ecological interpretation of resilience is characterized by the ability to adapt and transform in response to disturbances. This definition engages the interconnectedness of social and ecological systems within the supply chain, which makes it more complex and unpredictable. Instead of aiming for one equilibrium, it emphasizes experimentation, renewal, and the capacity to navigate uncertainty and change.

To some degree, supply chains still retain certain attributes of engineerable systems, because the individual organization is a controllable node within the ecosystem (Wieland & Durach, 2021, p. 320). Consequently, the foundational influences of both engineering and social sciences on supply chain management must continue to complement each other in the future. Therefore, the final and following definition of Walker (2020) of SCRES will be used within this research, captivating a social-ecological resilience sense:

"Supply chain resilience is the capacity of a supply chain to persist, adapt, or transform in the face of change." Walker (2020)

2.2 Supply chain resilience capabilities

Within the supply chain network, the individual node is to a certain degree engineerable by the supply chain manager (Wieland & Durach, 2021, p. 320). Therefore, operationalization of strategies to enhance SCRES is of importance to help build SCRES in practical application (Ali et al., 2017, p. 17). Strategies to enhance SCRES are generally characterized by the moment of implementation in the timeline of disruptions proposed by Sheffi and Rice Jr (2005, p. 43). A systematic literature review by Tukamuhabwa et al. (2015, pp. 11-13) categorizes

SCRES strategies by moment of implementation as before disruption and after disruption, which can subsequently be seen as proactive and reactive SCRES strategies. Tukamuhabwa et al. (2015, pp. 11-13) acknowledges that there is a certain grey area, in which strategies are implemented during disruption, but were initiated during a disruption. Previous research by Sheffi and Rice Jr (2005, p. 43) and Scholten et al. (2014, p. 216) categorizes these strategies as first response, and immediate response, as part of reactive strategy. Ali et al. (2017) covers this grey area adapting to the classification as defined by Hollnagel (2011, pp. 275-296). Here, the timeframe of when a disruption is happening is introduced, as concurrent SCRES strategies. Furthermore, the same disruption of pre-disruptive and post-disruptive categorization of SCRES strategies as Tukamuhabwa et al. (2015, pp. 11-13) is utilized.

Continuing to delve deeper into the hierarchical levels of SCRES, Four different capabilities are constructed to earlier definitions defined in the paper: 'safety resilience' by Hollnagel et al. (2009): the ability to anticipate, to monitor, to respond, and to learn. Three of the four definitions are used in the framework of Ali et al. (2017, p. 28), where the ability to monitor is categorized to the ability to anticipate, allowing for the introduction of the ability to adapt, referring to the dynamic sense of a supply network (Ali et al., 2017, p. 23). When utilizing a proactive SCRES strategy, it is imperative to build capabilities before a disruption occurs. Doing this allows the organization for the ability to anticipate on disruptions, and the enabling of adaptation when a concurrent SCRES strategy is deployed. Concurrent SCRES strategies are deployed during the disruption, and are aimed to enable the ability to adapt, and following up the ability to respond. Proceeding the model, reactive strategies are implemented to enable the ability to recover and the ability to learn. Ultimately, enabling the capability to anticipate is imperative to being more resilient, as it enables all other SCRES capabilities, and ultimately leads to higher SCRES levels.

Using the theoretical lens of Wieland and Durach (2021, pp. 315-320), and the social-ecological definition of SCRES, SCRES capabilities as described by Ali et al. (2017, p. 28) are classified between dimensions enhancing the ability to adapt, and capabilities that help return the supply chain to the equilibrium in past state. These categorizations are made by the researcher, and are shown in table 1 below.

SCRES DIMENSIONS	Description	Themes in SCRES	SCRES capabilities	SCRES perspective (Wieland & Durach, 2021)
Ability to anticipate	Proactive capabilities necessary to identify and monitor potential events, changing environments, and performance before the ability of the supply chain to function is affected	Proactively plan, anticipate risk, prepare, resist, avoid and be alert	Situational awareness Robustness Visibility Security Knowledge management	Social-ecological
Ability to adapt	Concurrent capabilities required to manage and adjust critical supply chain resources continually during disruptions and/or normal business activities.	Cope with unexpected disturbance or change, absorb/withstand/reduce impact, tolerate, adapt	Flexibility Redundancy	Social-ecological
Ability to respond	Concurrent capabilities needed to react to supply chain events on time and efficiently, to lessen the impact of disruptions or change the effects to ensure a desirable outcome	Maintain control, retain structure and function, react, change rapidly and respond.	Collaboration Agility	Mixed
Ability to recover	Reactive capabilities essential in the aftershock of a supply chain event, so as to restore or return to normal operations	Survive, maintain continuity, bounce back, return to original/normal state, move to new/desirable state, recover, restore quickly, in timely fashion, and cost- effectively and resume operations	Contingency planning Market position	Engineering
Ability to learn	Reactive capabilities required after a supply chain event to understand what has happened and improve future performance based on the experience	Sustain, growth, thrive, evolve, future adjustments and profitability	Knowledge management Building social capital	Engineering

Table 1 - SCRES: capabilities and different dimensions

As can be seen from Table 1, the primary emphasis of social-ecological resilience lies in the ability to anticipate and adapt. The ability to anticipate enables the ability to adapt (Ali et al., 2017, p. 28). Therefore, a key activity in enhancing SCRES should be the focus on enhancing the ability to anticipate. Ali et al. (2017, p. 28) mention five essential proactive elements and their different practices: situational awareness, robustness, knowledge management, visibility and security. One key aspect of situational awareness is having insights in organizational and supply chain capabilities, which affects the way a system adapts to a disruption (Vlahakis et al., 2018, pp. 86-87). This can be done by filling in a SCRES survey, as conceptualized in the project Next Gen Resilience (NGR). In this project, five SCRES capabilities are described: visibility, redundancy, flexibility, agility and collaboration, these capabilities are subdivided for downstream, internal and upstream capabilities that foster SCRES. These capabilities will also be the scope of this research, which will be described in the following paragraph. The

SCRES capability flexibility will be described in the following subchapter in this literature review.

Visibility as a capability of SCRES, refers to the information technology capabilities which are deployed before a disruption, to provide visibility for inventory and demand levels, materials flows (tracking and tracing), and detection of disruptions. These practices to enhance SCRES should be employed further than solely first-tier suppliers and customers to signify a bigger improvement in resilience (Jüttner & Maklan, 2011, p. 248) . Redundancy as an enabler of SCRES, is defined as "the strategic and selective use of spare capacity and inventory that can be used during a crisis to cope with supply and demand fluctuations" (Tukamuhabwa et al., 2015, p. 13). Organizations often use safety stock, backup suppliers, or utilize excess capacity in case of a disruption (Sheffi & Rice Jr, 2005, p. 44). Strategies that relate to redundancy see significant effect in short-term responses but lack value when facing long-term disruptions. Investing in strategies that promote redundancy is seen as costly for organizations, as it often heavily impacts working capital funds (Pettit et al., 2019, p. 61). Flexibility is defined as: "Supply chain flexibility is the capacity of all supply chain participants to adapt or respond to environmental unpredictability and fulfil a growing diversity of customer demands without incurring excessive costs, time, organizational disturbances or performance losses" (Manders et al., 2016, p. 183). This capability will be further evaluated in the following chapter.

Agility as an enabler SCRES pertains to the speed at which available options can be implemented and reached out to. Agility can be defined as: "the agility of a supply chain to rapidly respond do change by adapting its initial stable configuration (Wieland & Wallenburg, 2012, p. 302). Agility refers to practices such as rapidly adjusting product portfolio; quickly adapting services, products, or processes; and swiftly reacting to supply-side changes (Wagner & Neshat, 2012, p. 2879). Where flexibility refers to the possibility to being adaptable, agility refers to the speed these alternatives can be reached. In literature, SCF is sometimes seen as an enabler for a supply chain to make use of its agility capabilities (Abdelilah et al., 2018, p. 2). Collaboration within supply chains is defined as "joint decision-making and cooperation at tactical, operational, or strategic levels among two or more supply chain members (Jüttner & Maklan, 2011, p. 251) To effectively address disruptions, practices such as information sharing, aligning incentives or synchronizing decision-making processes are implemented to improve collaboration (Cao et al., 2010, p. 6614). Azadegan and Dooley (2021, p. 19) highlight the presence of various collaboration types within and across supply networks and emphasize the crucial role of network ties in fostering SCRES.

2.3 Supply chain flexibility

To be able to anticipate to risk and adapt to changes quickly in supply chains, flexibility plays a pivotal role (Ali et al., 2017, p. 25; Day, 2014). Increasing flexibility not only enables the opportunity to adapt to changes effectively, it also helps with operational efficiencies in normal-state conditions (Sheffi & Rice Jr, 2005, p. 41). SCF can be seen as the extent to which chains can alter their operations, speed, volume and place, parallel to the changes the market requires (Duclos et al., 2003, p. 23). Possessing SCF can be seen as a competitive advantage, as it enables firms to adapt to changing supply and demand conditions, allowing them to effectively present and adjust products to meet customers' needs (Jin et al., 2014, p. 25). Essentially, SCF can be captivated in the following definition: "Supply chain flexibility is the capacity of all supply chain participants to adapt or respond to environmental unpredictability and fulfil a growing diversity of customer demands without incurring excessive costs, time, organizational disturbances or performance losses" (Manders et al., 2016, p. 183).

Multiple authors have discussed the different aspects of SCF. Because of the complexity and interconnectedness of supply chains there are various views on this topic to be found. Vickery et al. (1999, p. 16) proposes five key dimensions from an operations perspective: Product flexibility, volume flexibility, launch flexibility, access flexibility and responsiveness to target markets. Vickery et al. (1999) focuses with these elements of SCF mainly on the single firm within the supply chain and neglects a certain network view. Taking these aspects of SCF as a foundation, and looking at further developments within constructs of SCF, Jin et al. (2014, p. 26) proposes five dimensions to take up- and downstream partners in consideration, contributing to a network view of SCF. For the aspects of flexibility of the focal manufacturing firm within the network, the author denotes three supply chain flexibilities. These are: product development flexibility, production flexibility, and logistics flexibility. Jin et al. (2014, p. 26) adds dynamic extensions on these internal flexibilities, by adding two more SCF dimensions: Suppliers' flexibility and supply base flexibility. Adding these two dimensions adds a holistic approach to SCF by expanding past the own organization.

A manufacturing firm's flexibility within a dynamic supply chain is essential for maintaining a competitive edge and long-term profitability (Stevenson & Spring, 2007). This flexibility involves the firm's capacity to efficiently and effectively adapt its product development, logistics, and production processes to changes in the external environment (Sreedevi & Saranga, 2017). Product development and production flexibility showcase a manufacturer's ability to manage new products and production processes (Zhang et al., 2002).

Logistics flexibility indicates the firm's capability to handle various receipt and delivery requests with precision, speed, and efficiency (Prater et al., 2001) These three functions, product development, logistics, and production, are closely interconnected. For example, production and logistics support is vital for successful product development, which in turn boosts the competitive performance of innovative products and significant modifications to existing products (Teece, 1986). Without such foundational support, these competitive advantages can quickly fade (Jin et al., 2014). Moreover, firms must quickly reconfigure their supply chains by fostering supplier collaboration to remain agile and responsive (Benzidia & Makaoui, 2020). Effective collaboration and robust support in logistics and production are crucial for maintaining competitive advantages in product development and adaptation.

With growing pressure on supply chains to respond adequately, organizational flexibility is not sufficient to cover all fluctuations in demand and supply. An extension is to be found in supplier's flexibility, which is necessary to take the intricacies of a dynamic supply chain into account (Mendonça Tachizawa & Giménez Thomsen, 2007, p. 117). Suppliers' flexibility is the ability of a manufacturing firm to swiftly and efficiently adapt their operations to meet a manufacturer's condition for components, and by doing this fulfilling the end customers' demand (Das & Abdel-Malek, 2003). Suppliers' flexibility enhances the manufacturing firm's flexibility, including product development, production and logistics (Forslund & Mattsson, 2021). Supply base flexibility refers to a firm's capability to modify its buyer-supplier relationships without incurring significant penalties in terms of cost, time, and effort (Ampe-N'DA et al., 2020). Supply base flexibility is found in the relationships between the manufacturing firm and its suppliers, unlike the flexibility within the manufacturing firm or the suppliers themselves. This flexibility is crucial because the overall performance of the supply chain relies on both the individual performance of each member and the efficiency of their interactions. Given the various ways to modify a buyer-supplier relationship, such as adding a new supplier, altering the closeness of the relationship, or redirecting orders to a different supplier, two key aspects of flexibility, range and mobility, are particularly significant (Jin et al., 2014; Stevenson & Spring, 2007). An overview of the different dimensions of SCF can be found in table 2 below.

Node	Dimension of SCF	Definition
Manufacturing flexibility	*Product development flexibility*	The ability to respond to changing customer needs with new products and modifications to existing products (Zhang et al., 2002).
	Production flexibility	The ability to produce a range of different (types of) products or fulfill different activities in a certain fixed situation (Stevenson & Spring, 2007).
	Logistics flexibility	The ability to align, adapt and adjust the process of the goods flow including the inbound and outbound activities and the storage of the goods to the changing customers' needs (Hock Soon & Mohamed Udin, 2011)
Network flexibility	*Suppliers' flexibility*	The ability of a manufacturing firm to swiftly and efficiently adapt their operations to meet a manufacturer's condition for components, and by doing this fulfilling the end customers' demand (Swafford et al., 2006).
	Supply base flexibility	The ability of a firm to modify its buyer-supplier relationships without incurring significant penalties in terms of cost, time, and effort (Gosain et al., 2004).

Table 2 - SCF: Different dimensions

Considering available research, adaptation and reconfiguration mechanisms are essential for enhancing resilience (Piprani et al., 2022, p. 310). Flexible systems contain an organic capacity, enabling it to address and respond to unexpected crisis affecting the network (Jüttner & Maklan, 2011, p. 251). Thus, building flexibility is essential for organizations to strengthen their manufacturing operations to deal with supply chain hick-ups (Sheffi & Rice Jr, 2005, p. 405).

3. Research Methodology: Mixed methods approach

This chapter contains aspects regarding data collection procedures, more specifically how, why, where, what and from whom the data was obtained.

3.1 Research design

This research responds to calls to develop more empirical research for SCRES (Ali et al., 2017, p. 19), and the need to implement a holistic social-ecological view of SCRES (Wieland & Durach, 2021, p. 320). To grasp on the complexity of SCRES, a mixed methods approach was used. This was done because this approach fosters triangulation, and support validity and reliability of the data, which is especially helpful in upcoming complex research topics where limited data is available (Noyes et al., 2019, p. 1). More specifically, a sequential explanatory mixed methods approach was taken. In this approach, firstly quantitative data is collected and analyzed, followed by gathering and analyzing qualitative data (Creswell et al., 2003). This approach was deemed suitable, because a guided theoretical perspective was available in the NGR scan , together with a population in which the data could be gathered (Almeida, 2018, p. 141). By having two instances where data is analyzed, the focus of the study can be trajected to the most relevant approach mid-way. This suits this master thesis study, as it addresses the complex construct SCRES, which is not realistic to fully cover in one thesis among multiple cases because of limited time available. Therefore, this thesis focuses on points of interest the quantitative data revealed. Disadvantages in using a mixed methodology may entail that synthesizing numerical data with thematic data can be challenging as they are different in nature. This can add certain complexity to the research, which leads to difficulties in drawing meaningful conclusions (Malina et al., 2011, pp. 3-8). This mixed methodology study is deductive in nature, in which the NGR survey is used to test SCRES capabilities among manufacturing firms. Following, the qualitative part is abductive. In which reasonings for the point of interest are explained by practitioners.

3.2 Quantitative approach - Survey

To determine SCRES capability levels among supply chains, the NGR scan has been used (Resiliencescan, 2024). This is a survey, designed for organizations within the process and manufacturing industry to fill in supply chain characteristics of their company and up- and downstream partners that contribute to SCRES. The unit of observation is the focal firm within the supply chain, whilst the unit of analysis is the supply chain. The view of the supply chain

is limited to focal firm plus tier -1 and +1. The choice of using this survey was made because this study is part of a broader research named 'Next Gen Resilience'. This broader research focuses on extracting different profiles of organizations, also, it aims to be able to benchmark SCRES among supply chains by gathering data on the five constructed SCRES capabilities (Resiliencescan, 2024). These five capabilities (Redundancy, collaboration, flexibility, visibility and agility) and the survey have been conceptualized in an earlier research program called 'Ready for the next crisis', in which 37 interviews and 35 surveys supported creating this holistic framework (Dinalog, 2023). Using a survey format to assess SCRES promotes rigid in the findings, as it offers a standardized tool to measure and compare capabilities across organizations (Evans et al., 2016). Offering this standardized tool enhances the generalizability of the study, as all respondents are part of a manufacturing organization. This results in data which is viable for the remaining part of this research.

3.2.1 Operationalization

This section outlines the operationalization of the NGR scan as is used within this research. The framework is used within the first part of the study, and a summary of the questionnaire can be found in table 3, the full questionnaire can be found in appendix A The survey is constructed for organizations present in the process and manufacturing industry, and focuses on assessing SCRES capabilities for upstream, internal and downstream nodes. This is done by rating the different items on a five-point Likert scale (1- not true in (almost) all cases to 5 – true in all cases).

Capability	**Upstream**	**Internal**	**Downstream**
Redundancy	Suppliers guarantee to keep extra buffer stock	Multiple DCs distributed geographically	Contracts offer the possibility to deliver 50% more or less
Collaboration	Problems are solved by joint teams	Culture of continuous learning and improvement	Investments have been made in a long-term relationship with a lot of openness and trust
Flexibility	Alternative transportation options, alternative suppliers available	Alternative sources of financing available	Flexible order fulfillment possible

Transparency	Major suppliers share production planning for at least the next 4 weeks	Decisions regarding operation, maintenance and logistics are supported by accurate and up-to-date data and models	Tracking & tracing information of shipped products is shared
Agility	Onboarding new suppliers can be done quickly	Processes are constantly being improved and can be adapted quickly	New products can be brought to market quickly (NPI)

Table 3 - Preview operationalization NGR scan

After filling in the survey, the respondent is also asked about the characteristics of the focal firm. This is done for the following aspects: Sector, subsector, size (number of employees, value strategy, where the power in the chain is, position in the value chain, B2B/B2C, # competitors, # suppliers, # customers, Customer order decoupling point, culture, type of company, geographical footprint supply network, geographical footprint customers.

3.2.2 Population and sampling

The unit of analysis within this part of the study are companies and their supply chains that are operating within the process and manufacturing industry. The unit of observation are individual supply chain managers that are knowledgeable on their company's supply chain capabilities. The pool of supply chain professionals that were reached out to are members of the Supply Chaingers community. This is a network of professionals with at least 10 years of experience in supply chain, who come together to discuss relevant topics and trends within the field of supply chain management. Sharing knowledge is one of the key drivers of this group of professionals. The Supply Chaingers community consists of 125 professionals, who all represent different organizations. These organizations vary in terms of industry and size but are all active in the process and manufacturing sector. The respondents are highly knowledgeable of their supply chain due to the position they have within their organization. Below in table 4, the characteristics of the enterprises can be found. The study has 85 respondents which is a 68% response rate, which were all interpreted as valid questionnaires for the data analysis.

Respondents position		**Percent**
	Supply Chain Manager	32,9
	Supply Chain Director	10,5
	Logistics Manager	10,5
	Procurement Manager	8,2
	Operations Manager	4,7
	Operations Director	4,7
	Supply Chain Engineer	3,5
	Logistics Director	3,5
	Director	3,5
	Other Supply Chain related roles	17,6
Size (employees)		**Percent**
	10-49	6
	50-99	11,9
	100-499	33,3
	500-999	14,3
	1,000-9,999	25
	10,000+	9,5
Value strategy		**Percent**
	Customer intimacy	31
	Operational excellence	22,6
	Product leadership	32,1
	Other (non-specified)	13,1
Position in the value chain		**Percent**
	Far upstream (raw materials)	3,57
	Upstream (semi-finished products)	22,6
	Center	41,7
	Downstream (Wholesale)	27,4
	Far downstream (Retail)	2,38

Table 4 - Respondents profile NGR scan

3.2.3 Data collection and analysis

Firstly, the population was introduced to the upcoming research by posting in the online community of the population. Following, the survey was made public to the population, and an email was sent out to invite the population to fill out the survey. The email starts with a request to fill in the survey and continues the benefits this gives to the potential respondent to get insights in their SCRES capabilities. Also, the reasoning that the results are being used for the next Supply Chaingers event was used in this email. Subsequently the data policy was mentioned, together with a statement that the author is willing to answer requests. Two weeks after this email a reminder was sent out to the population that had not already filled in the survey. After this, one last email was sent out before the closing date to gather respondents. A day before the closing date, the researcher personally called the population that had not filled in the survey. After conducting the survey, the data was thoroughly cleaned and prepared for analysis using R, a powerful statistical software. The cleaning process involved removing any incomplete responses, handling missing data, and ensuring consistency in the data entries. Data was gathered on three SCRES levels, upstream, internal and downstream. These results were combined to one total SCRES level for each capability, to create an aggregate level of SCRES for each organization on the different capabilities. This was done because the primary objective was to investigate differences in means between the different capabilities within the dataset. To achieve this, an independent two sample t-test was utilized, which is a statistical method that determines whether there is a significant difference between the means of two independent groups. This involved checking the assumptions of the independent two sample t-test, including normality and homogeneity of variances, using Shapiro-Wilk test and Levene's test, to ensure the validity of the results. The Shapiro-Wilk test was used to check normality of the data, in which the results can be seen in Table 5 below.

Capability	**Shapiro-Wilk Statistic**	**Shapiro-Wilk P-value**
Redundancy	0,98	0,59
Collaboration	0,98	0,43
Flexibility	0,98	0,49
Visibility	0,96	0,008
Agility	0,95	0,009

Table 5 - Shapiro-Wilk test results for normality of capabilities

The table indicates that the p-values for the capabilities visibility and agility are 0.008 and 0.009, which is less than the threshold of 0.05, suggesting that the data is not normally distributed. However, bearing in mind that this study considered a sample size of 85, the Central Limit Theorem holds in this case. This theory explains that for a large enough sample size, the sampling distribution of the mean tends towards a normal shape, even when the original data distribution is non-normal (Kwak & Kim, 2017). Considering that the sample size being larger than the often-considered size of 30, this provides theoretical evidence to go ahead with parametric testing methods, such as the t-test, even if non-normality has been demonstrated by the Shapiro-Wilk test.

To ensure the validity of parametric statistical tests, Levene's test was conducted to assess the assumption of homogeneity of variances across the capabilities being studied: Redundancy, Collaboration, Flexibility, Visibility, and Agility. The results, presented in Table 6, show the p-values for each comparison. For most comparisons, the p-values are above the threshold of 0.05, indicating that the assumption of equal variances holds. However, some comparisons, such as collaboration vs. flexibility ($p = 0.009$) and flexibility vs visibility ($p = 0.01$), display p-values below 0.05, suggesting significant differences in variances. Despite these findings, the decision was made to proceed with the standard independent two-sample t-test for all comparisons. This choice is justified by the robustness of the t-test to moderate deviations from the assumption of equal variances, particularly given the relatively large sample sizes involved in this study. However, the results should be interpreted with caution, particularly for comparisons where Levene's test indicated unequal variances.

	Redundancy	**Collaboration**	**Flexibility**	**Visibility**	**Agility**
Redundancy		0,15	**0,31**	0,15	**0,18**
Collaboration	0,15		**0,009**	0,89	0,15
Flexibility	**0,31**	**0,009**		**0,01**	**0,31**
Visibility	0,15	**0,89**	**0,01**		0,16
Agility	**0,18**	0,15	**0,31**	0,16	

Table 6 - P-value matrix from Levene's test for homogeneity of variances

3.2.4 Data reliability and validity

To ensure validity of the constructs used in this study, a confirmatory factor analysis (CFA) was conducted., the results are summarized in table 7 below. Each node (Upstream, Internal,

Downstream) represents the different parts of the supply chain the NGR scan measures, and the constructs measured included redundancy, collaboration, flexibility, visibility and agility.

Node	Redundancy	Collaboration	Flexibility	Visibility	Agility
Upstream	0,55	0,88	0,8	0,77	0,71
Internal	0,7	0,57	0,5	0,7	0,69
Downstream	0,65	0,81	0,53	0,76	0,79

Table 7 - Standardized factor loadings for constructs across supply chain nodes

The results indicate the standardized factor loadings for each construct across the different nodes. These factor loadings represent the strength of the relationship between the observed variables and their respective latent constructs. According to Hair Junior et al. (1998) factor loadings in Confirmatory Factor Analysis (CFA) can be interpreted as follows: loadings of 0.7 or higher are considered strong, loadings between 0.5 and 0.7 are considered moderate, and loadings below 0.5 are considered weak. Considering table 7, all constructs of redundancy, collaboration, flexibility, visibility and agility are validly measured across the supply chain nodes, with generally strong to moderate factor loadings, indicating the validity, and particularly the construct validity of the measurement model.

To ensure data reliability, Cronbach's alpha was calculated for the different capabilities of SCRES, which can be seen in table 8 below. This was done by grouping upstream, internal and downstream capabilities into the different capabilities, as construct validity was ensured by conducting a PCA. According to George and Mallery (2019), Cronbach's alpha values can be interpreted as follows: values greater than 0.9 indicate excellent reliability, values greater than 0.8 indicate good reliability, values greater than 0.7 are considered acceptable, values greater than 0.6 are considered questionable, values greater than 0.5 are considered poor, and values below 0.5 are considered unacceptable.

	Cronbach Alpha
Redundancy	0,67
Collaboration	0,78
Flexibility	0,63
Visibility	0,82
Agility	0,77

Table 8 - Cronbach's alpha values for capability reliability

Using these thresholds, the results presented in Table X indicate the reliability levels for each construct measured within the SCRES framework. The capabilities collaboration, visibility

and agility all show acceptable or good reliability. However, redundancy and flexibility show questionable reliability. While these values are slightly below the generally accepted threshold of 0.7, they can still be considered adequate for exploratory research, which aligns with the primary goal of this study.

3.3 Qualitative approach – World café

To find out why organizations experienced it to be more difficult to build the capability SCF, a WC was deemed appropriate similarly to the set-up described in the paper by Schiele et al. (2022). The WC is a flexible and time-efficient method that enhances collaborative conversations and sharing knowledge. The café is a group activity that leverages the dynamics of small group discussions to give insights and collective understanding on a specific topic of interest (Schiele et al., 2022). One key consideration for selecting a WC set-up, is the large amount of data which can be generated in a short amount of time, which suits the timeline of a master thesis. Within the WC, all five capabilities of SCRES were included, but only the capability flexibility was considered for further analysis. By conducting this WC, insights are gathered in what methods practitioners are aware of to build SCF, and what the biggest difficulties are in adapting to these measures. In figure 1, the outline of the set-up is visualized.

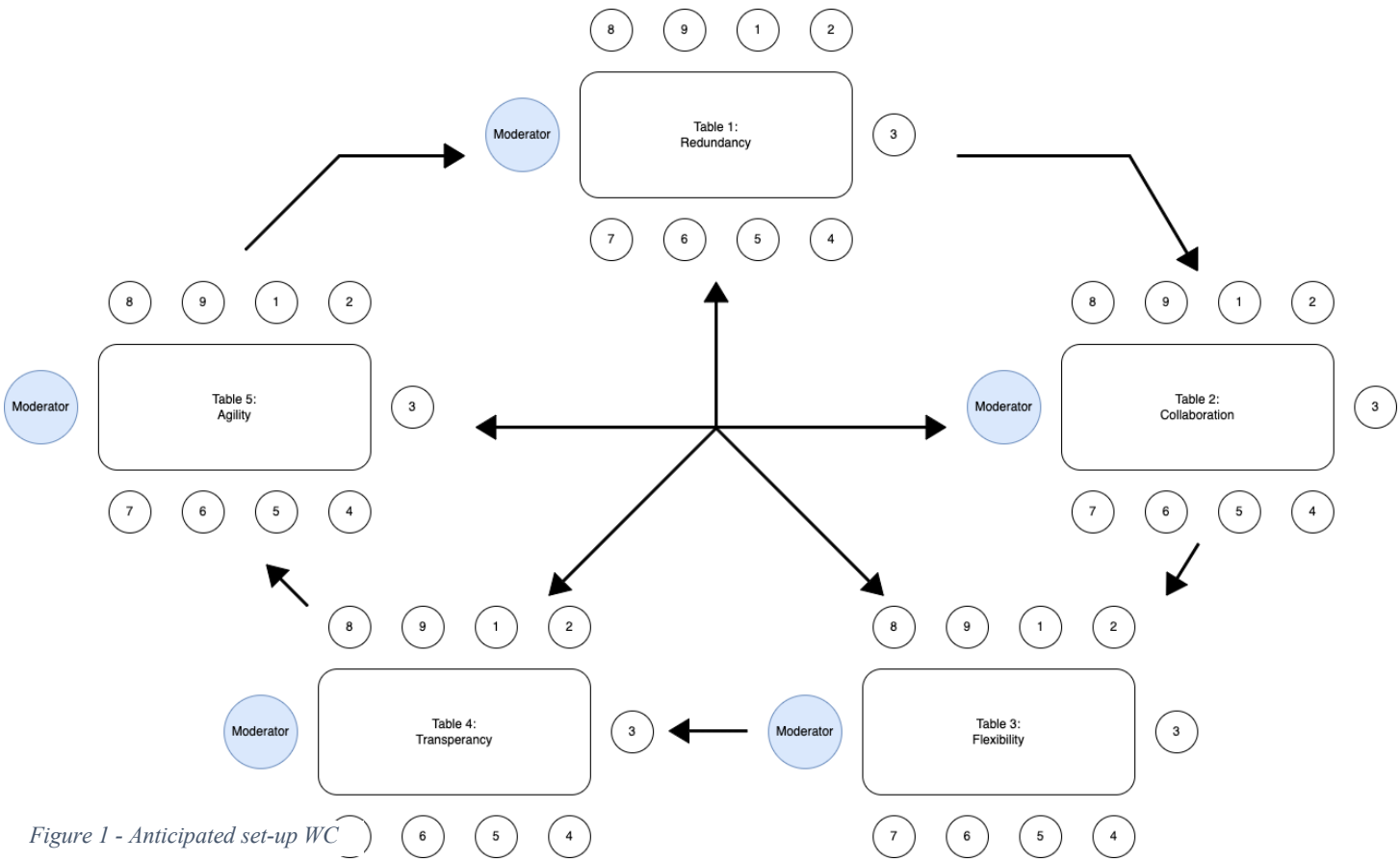

Figure 1 - Anticipated set-up WC

3.3.1 Operationalization

Typically, four discussion rounds are organized within a WC (Schiele et al., 2022). Because of the limited time available during the workshop, the researcher chose to limit this to three rounds of discussion. At the start of each round, the researcher introduces the construct SCF, and the results that came forward from the quantitative section of this research. Also, the results of previous rounds (applicable for round 2 and 3), are summarized and told to newly joined participants to have shared knowledge, which helps to steer the discussion in the right direction. During the debate, the researcher is responsible for the notation of the discussions that happen throughout the different rounds. Between these rounds, one A2 paper was present on the table to visually capture the trail of thoughts that evolve during the conversations. As this research focus on overcoming difficulties in building SCF, the first round discussion focusses on idea generation of practitioners in how SCF can be build. This leads to a list of potential methods for manufacturing firms, in how they can build SCF. Following, the second and third round cover the difficulties organizations might have adopted these SCF methods. Table 9 below shows an overview of the different rounds of the WC.

Round	Goal	Activity	Time
1	Extracting methods to build SCF	Brainstorming	15 minutes
2	Addressing difficulties in using methods given in round 1	Brainstorming and discussing	15 minutes
3	Addressing difficulties in using methods given in round 1	Brainstorming and discussing	15 minutes

Table 9 - Overview of the WC discussion rounds

3.3.2 Population and sampling

The unit of analysis are companies and their supply chains that are operating within the process and manufacturing industry and have filled in the NGR scan in the quantitative part of the study. The unit of observation are supply chain managers who are knowledgeable on their firm's supply chain. Not all participants of the Supply Chaingers community were present on the day of the gathering. Only members who applied via email were considered for the WC discussions. 45 Supply chain managers applied for the Supply Chaingers meet-up, and 38 of them had filled in the NGR scan, which is seen as the population. The main goal of this methodology is generating a lot of thoughts around the topic of SCF. Ideally, this is done in

groups of 4-6 participants (Schiele et al., 2022), but because of an attendance of 45 participants and five available topics in SCRES capabilities, a group size of 9 participants was chosen. This group size is sometimes seen in focus-groups (Howell, 2012), which also has characteristics of a WC(Schiele et al., 2022).

To determine the composition of participants of the different groups for the different rounds, deterministic sampling was used, more specifically quota sampling. Deterministic sampling is a method of sampling where the selection of elements from the population is entirely determined by a specific rule (Lavrakas, 2008). Quota sampling is the act of selecting a specific number of participants within certain categories based on predefined characteristics or criteria to ensure that different subgroups are well represented (Lavrakas, 2008). In this case, the aim is to get the average SCF score of the sub-groups close to the total average SCF scores (2,36) as possible. This was done to promote generalizability of the results. An outline of scores of the different groups can be seen in table 10.

Participant	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**AVG**
SCF Score (Group 1)	2,11	2,86	2,83	1,25	1,61	2,36	3,04	2,68	1,31	**2,23**
SCF Score (Group 2)	1,41	3,36	1,33	3,27	1,28	2,14	1,61	2,76	2,46	**2,18**
SCF Score (Group 3)	1,99	2,33	2,08	2,27	2,01	3,05	2,31	2,3	3,25	**2,4**

Table 10 - SCF scores of participants across different rounds by group

3.3.3 Data collection and analysis

The schedule and topics were verified with the supervisor from Evofenedex, as well as the supervisor of the University of Twente. The setting of the discussion will take place at five tables, located within an open corporate cafeteria. Every discussion started with a plenary explanation of the construct SCF and the aims of the research. During the discussions in the different rounds, the A2 paper was the guiding principle for data collection. The researcher captured key points, ideas and connections made by participants during the discussions. During the first round, methods to build SCF were written in the center of the A2, following up, in the second and third round the difficulties in utilizing these methods were connected. Utilizing the A2 paper helped to actively engage participants and provided a tangible record of the group's

insights. After the event, all discussions were transcribed and translated to prepare for further analysis. For organizing the different methods and difficulties, ATLAS.ti was used. Aggregate dimensions of SCF were used as conceptualized in the literature review, and the different methods were first linked to the different dimensions. Following, the difficulties that were observed were linked to the different methods.

3.3.4 Data reliability and validity

Various measures to enhance reliability and validity are taken. Reliability of a study refers to the consistency of the research and to which extent the same results can be replicated under similar conditions. This study ensured reliability by structuring the WC as close to the established guidelines by Schiele et al. (2022), with predefined rounds of discussion and clear goals for each round. Quota sampling was used to promote generalizability and reliability and shows a quantitative identification of each participant which can be replicated. Furthermore, the researcher was invested in the topic of SCF, and thus well briefed before moderating the discussion, which led to less room for interpretation of results. The transcription and coding were done in a systematic manner, where the data was linked to one of the dimensions conceptualized in the literature review. To promote validity in this research, the construct of SCF was clearly defined and operationalized based on established literature. Before each discussion, participants were briefed with a detailed explanation of SCF and its dimensions to ensure mutual understanding. The topics were designed together with both supervisors to make sure these aligned to the research question. Internal validity was ensured by using quota sampling, and making sure the characteristics of the sample aligned with the characteristics of the overall population in terms of their SCF scores.

3.4 Qualitative approach – Expert interviews

Expert interviews were adopted within this part of the research to delve deeper into the topic of SCF. More specifically, ways to overcome difficulties that were observed in the WC were addressed during these interviews. Semi-structured interviews offer flexibility to dig deep into specific areas of expertise, which may emerge unexpectedly during the conversation, which is important in a complex and dynamic field like SCF (Gill et al., 2008; Kallio et al., 2016). This format is especially appropriate for getting insights from experts, many of whom are likely to have multifaceted views and experiences. It allows for a more natural flow of discussion, where participants feel freer to express their thoughts on discovering new and different dimensions of the topic that were not considered earlier (Gill et al., 2008). This ensures a comprehensive understanding of how to overcome the difficulties identified in the phase of the WC and is a valuable methodology for exploring the realm of SCF.

3.4.1 Operationalization

The operationalization of the semi-structured interviews is based on the methodologies and difficulties that were extracted in the WC. Table 11 shows the difficulties together with the operationalization of the interview questions that were chosen to get to know more about the observed phenomenon. The full interview protocol and schedule can be found in appendix B.

Dimension SCF	**Difficulties mentioned in world café**	**Interview questions**
Product development flexibility	"Our sector makes customer specific products, there is no room for flexibility in terms of products in and out. Our machines are specifically set-up for each customer and a certain supply that is designed for this customer. Changing products based of materials of a different supplier is too costly."	Does your organization work with customers that require customer-specific products? If so, how does your company manage to be flexible to meet this changing customer demand? What processes or technologies help in adapting to customer-specific requirements?
Production flexibility	"We have difficulties becoming flexible, because our company is very much influenced by seasonal demand. This is because of seasonal climate changes mainly" "Our company is mainly focused on operational efficiency. Our machinery is operating on near maximum capacity, especially during peak moments in production. Limited flexibility is available at those moments."	Seasonal demand fluctuations have been noted as a significant challenge in building SCF. How does your company manage these fluctuations? Balancing operational efficiency with flexibility is crucial. How does your company ensure that machinery and production processes remain flexible, especially during peak production periods?
Logistics flexibility	"Our products have strict safety regulations, limiting us to specific transport modalities and preventing easy switching to unfamiliar partners."	Are there products that need a special logistic/transportation approach? How does your organization manage flexibility with these products?
Suppliers' flexibility	"Flexible supply contracts are difficult to maintain in the long run. Costs are higher and you lose margin compared to other competitors. Essentially your business is losing competitive advantage." "Difficulties in communication, resulting to less flexibility. Because of one contact person who is not high-up in the company, we have less communicative power, and thus a less competitive position for flexibility in the supply of our goods"	Flexible supply contracts are difficult to maintain due to higher costs and potential margin losses. How does your company handle flexible contracts while staying competitive? One of the challenges identified is difficulties in communication, especially when dealing with less influential contacts within supplier companies. How has your organization addressed this issue to enhance flexibility in your supply chain?
Supply base flexibility	"We considered dual sourcing, but the second supplier couldn't meet our required quality, making it impractical for our operations and customer demands." "Dual sourcing is challenging due to increased CSRD and CSDD compliance, doubling the suppliers we need to monitor." "Past dual sourcing efforts showed limited power in relationships, making it ineffective during supply chain disruptions."	Dual sourcing has been identified as both a potential solution and a challenge to build SCF. How has your organization managed dual sourcing to ensure quality and compliance required?

Table 11 - Difficulties mentioned in world café and corresponding interview questions

3.4.2 Population and sampling

The unit of analysis are focal firms within a supply chain context. These firms operate within the process and manufacturing industry. The unit of observation are supply chain managers representing these focal firms. In table 12, the respondent profiles can be found. The population consists of supply chain managers, and persons with knowledge of SCF and their company's supply chain. For the sampling technique, purposive sampling is used. Purposive sampling is helpful to gain deeper insights in specific phenomena and ensures relevance to the topic of SCF. Using purposive sampling also helps with efficiency, as the researcher can select the sample that generates the best insights (Creswell & Poth, 2016). Disadvantages to purposive sampling entail that a certain bias can occur because the researcher's judgement is used to select the sample. Also, the generalizability of the data is limited due to the non-randomness nature of purposive sampling (Creswell & Poth, 2016). These disadvantages were combatted by selecting respondents on relevance criteria. Respondents 1 and 2 were chosen because of their experience in academics in the field of supply chain management, more specifically in disruption management. Respondent 3 was approached because of a high score on the NGR scan on SCF, which helped with extracting best practices.

Respondent pseudonyms	**Job title**	**Experience**	**Sector**	**Firm size (employees)**	**Time duration**
R1 - (Company A)	Supply Chain Manager	7 years	Manufacturing: Food	100-499	42:03
R2 – (Company B)	Business Development	9 years	Manufacturing: Automotive	1000-9999	48:04
R3 – (Company C)	Value Supply Chain Manager	17 years	Manufacturing: Food	500-999	52:43

Table 12 - Respondent profiles and interview details

3.4.3 Data collection and analysis

The structure of the interview protocol is based on the three segments as mentioned by Seidman (2006). The interview starts with an introduction, followed up by the main body of the interview, and is concluded by a conclusion section. The protocol can be found in appendix B. The interview protocol is reviewed together with the supervisor to ensure completeness and an appropriate duration. All interviews are taken through a Microsoft Teams meeting, because of efficiency reasoning. To get started, in each of the interviews, an introduction was made by the

interviewer, including the objective and purpose of the research and the interview; clarification of anonymity; and confidentiality and request to record the interview. The input derived from the interviews is transcribed, checked, and verified with the respondents. After the transcription, basic thematic analysis is performed to find reoccurring themes. The study is explorative in nature, but still finds communalities in the interviews, which are found by coding the interviews based on a structure of Saldaña (2021), where themes, topics and codes are linked to each other.

3.4.4 Data reliability and validity

The reliability and validity of this research were ensured through several methodologies and systematic processes. To ensure that it was reliable, a standardized semi-structured interview protocol was adopted in guiding the process but flexible in questioning other topics that may emerge relevant to SCF. Reliability was also enhanced by recording interviews, transcribing**,** and verifying with participants to ensure accuracy and consistency in collecting data. A structured approach in thematic analysis, combined with systematic coding according to Saldaña **(**2021**)**, ensured that the homogeneity of data interpretation was maintained. Addressing content validity was supported by basing questions during interviews on challenges identified in the WC phase earlier, thereby ensuring that the questions are relevant and drive the research at hand. Purposive sampling in the study primarily targeted experts with specific knowledge of SCF, which enhanced validity by gathering relevant and insightful data. Triangulation of responses across various participants does confirm consistency of findings, thereby building the overall credibility of conclusions made from the research. On the other hand, the researcher is aware of the small sample size of three respondents. Therefore, this part of the study can be interpreted as explorative.

4. Results

In this chapter the results are presented. Firstly, by zooming in on the quantitative results of the NGR scan, followed up by the results of the WC on methods to create flexibility and the difficulties that are experienced in this. To conclude, expert interviews are introduced to see how organizations handle these difficulties in their way to become flexible.

4.1 Assessing SCRES – quantitative results

In table 13 below, the descriptive statistics on each of the five different capabilities that are measured within the NGR scan. Averagely, flexibility is the lowest scoring capability, and agility the highest. The biggest variance within capability scores is found in visibility, and the least for redundancy. The highest value can be attributed in the visibility capability, and the lowest for agility.

Descriptives	**Redundancy**	**Collaboration**	**Flexibility**	**Visibility**	**Agility**
Average	2,61	2,79	2,36	2,81	3
St. dev	0,5	0,69	0,52	0,76	0,63
Min Value	1,19	1,36	1,25	0,95	0,92
Max Value	3,78	4,35	3,66	4,47	4,44

Table 13 - Descriptive statistics for SCRES capabilities

Looking at interrelations between different capabilities, an independent two sample t-test has been utilized. The results can be found in table 14. As can be seen, a p-value of <0,05 is observed between the mean of redundancy and agility. This shows the means of these capabilities are significantly different to each other. When looking further at other relationships between capabilities, p-values lower than 0,05 are to be seen in every capability related to flexibility. This indicates a significant distinctive characteristic for flexibility, in which it contributes to concept of SCRES differently than the other capabilities, marking an area of interest, especially because the average from this capability is the lowest scoring.

P-value matrix independent two sample T-test

	Redundancy	**Collaboration**	**Flexibility**	**Visibility**	**Agility**
Redundancy		0,06	**<0,001**	0,05	**0,002**
Collaboration	0,06		**<0,001**	0,82	0,05
Flexibility	**<0,001**	**<0,001**		**<0,001**	**<0,001**

Visibility	0,05	0,82	**<0,001**		0,09
Agility	**0,002**	0,05	**<0,001**	0,09	

Table 14 - P-value matrix for t-tests across scres capabilities

Reviewing the different items that belong to the construct of flexibility, contributing to overall SCRES. The different items can be seen in table 15 The complete explanation of all codes and the corresponding items can be found in appendix A. One item to specifically note is In – F3, which has the lowest average (1,59) of all items. In – F3 refers to the following survey question: 'Processes and sequence/route of production operations can be easily modified'. A bar chart is presented in Figure 2, highlighting the differences in scores for clear visual comparison.

Item	**Average**	**St. dev**
Up - F1	2,29	1,4
Up - F2	2,16	0,96
Up - F3	2,35	0,98
Up - F4	2,45	0,99
(Up – F)	***2,31***	***1,08***
In - F1	2,78	0,83
In - F2	2,26	1,13
In - F3	1,59	1,24
In - F4	2,75	1,23
(In – F)	***2,35***	***1,1***
Do – F1	2,40	0,84
Do – F2	2,52	1,07
Do – F3	2,54	1,11
Do – F4	2,54	1,14
(Do – F)	***2,5***	***1,04***

Table 15 - Items scored for flexibility

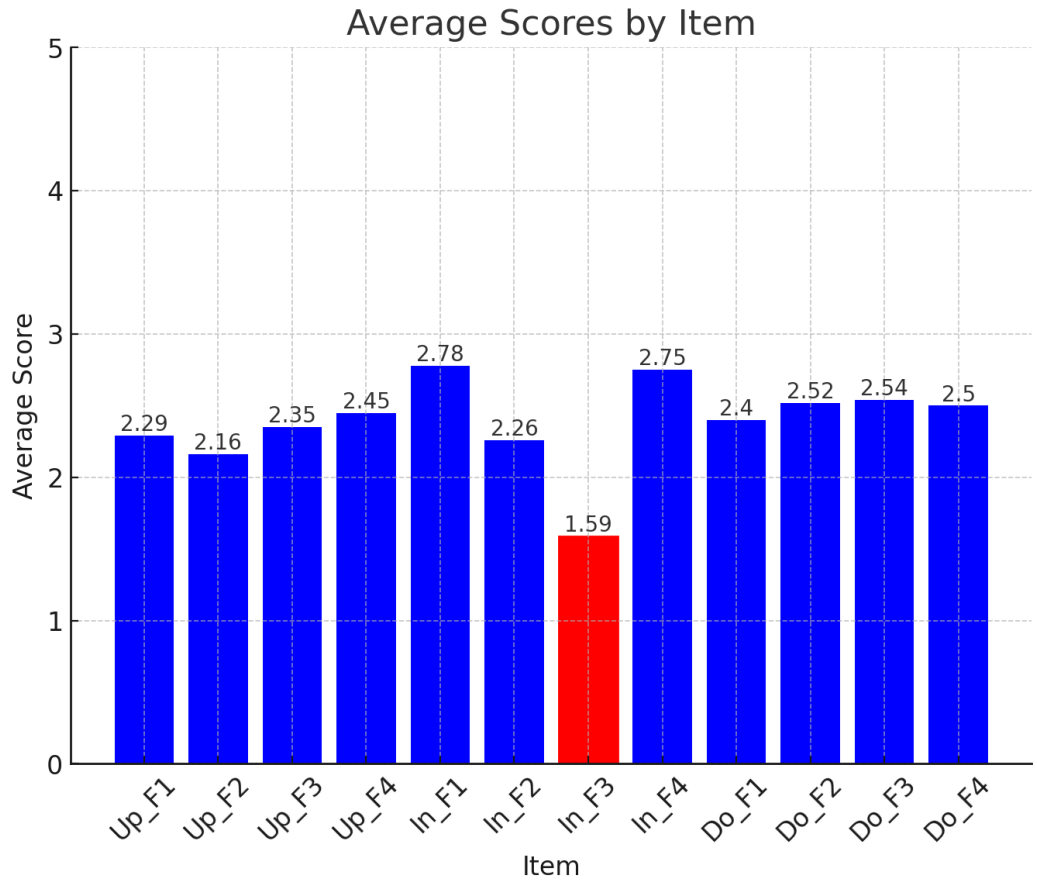

Figure 2 - Items scored for flexibility

4.2 Building flexibility – qualitative results

In this subchapter, the results on how to build SCF, the difficulties that come with using these methods, and how to overcome these difficulties are described. These results are found by performing a WC and expert interviews. The results are segregated to the different dimensions of SCF as described by Jin et al. (2014).

Product development flexibility

Product development flexibility is the ability to respond to changing customer needs with new products and modifications to existing products (Zhang et al., 2002). When discussing the topic of product development flexibility during the WC, participants highlighted significant constraints in developing product development flexibility, primarily due to the nature of products and processes. One participant mentioned, *"We are working with make-to-order (MTO) products which doesn't allow us to be flexible in planning our demand, which means that we have to have more stock and have a less linear process, resulting in less flexibility."* This quote indicates that the customization and specificity required in MTO strategies limit the ability to adapt quickly to changes in demand, and thus hinders enhancing product development flexibility. Expert interviews revealed several strategies to minimize the impact of customer specific products on SCF. One respondent operating for company B highlighted their successful strategy revolves around product design optimization: *"We are working with a MTO strategy. The basis of our success in flexibility lies in the fact that our products and components are modular, so all components fit together. This means we are flexible in production and can have late changes to our orders. When certain stock is not available, we can source from other production facilities around the world, who share the same components"*. Having modular components involves optimizing product design, standardizing components, whilst not limiting customer specific products. This is a successful solution, however, is not possible for all organizations due to product complexity.

A respondent working for company A, mentions the characteristics of their products do not allow them to have high product development flexibility: *"We are in the food-industry, so in that sense we have product restrictions because of nutritional values and packaging etcetera. If we change an ingredient, this goes completely through the chain. Which has major implications"* In this case, optimizing product design is difficult, because of the complexity of the end-product. Finding flexibility can be found in limiting product availability: *"More and more we are telling our customers that a certain product is not possible to be delivered, but a*

close substitute is. We're doing a portfolio review where we try to think together with the customers if we can offer them other products or ingredients". This quote indicates creating flexibility in your customer demand by communicating fewer options in customer-specific products, which also is in relation standardization of products. To enable product development flexibility communication is essential: *"To overcome problems with our MTO products, we make better agreements with customers about our production sizes in the factory. We are then talking about minimum-order-quantity, also to be more efficient in the factory, also because we must deal with changeovers in production."* A respondent from company C mentions their operations are solely make to stock: *"We are working with make to stock products, because we are so big. We make to stock, and then see when it gets sold."* Company C works within a linear supply chain with fixed goods in, and out, which gives them flexibility because of a stable demand in number of types of products. Looking at company A and B, we see customer specific demand which increases their need for adaptability to this specific demand. Company A works with complex products, which limits their potential of standardization, where company B can succeed in modular product design because of less restrictions in their product design.

Another way to deal with customer specific demand is to make use of buffers, Company B mentions: *"Because of changing customer demand you cannot avoid naming stock to become flexible. However, we try to keep this at a 'minimum'.* In their way of trying to keep this at a minimum, company B mentions the following procedure: "*We always send a yearly forecast and try to avoid late changes in this, because if you do that too often you lose trust with you supplier. This builds a bit of buffers, but keeps a good relation, so that in case a disruption happens you have a bit of buffers and a good relationship with the supplier'.* To keep a balance in buffers, company B further mentions: *'Every now and then we do a cycle to critically assess if safety stock can go down to save on costs in buffers".* Company A mentions customer-specific stock and dealing with goods that can expire: *"Because of customer specific orders we need a lot more stock, to handle these different customer demands, which also results in the risk the customer specific stock not always being taken"* Because of this, critically assessing inventory, and having clear agreements is of big importance. A recent project introduced is: *"To overcome problems, we make better agreements with customers about our production sizes in the factory. We are then talking about MOQ, also to be more efficient in the factory, also because we must deal with changeovers in production".*

Zooming out on the results, a relation between customer specific products and flexibility is described, with complexity of products having an effect. At company B we see a less complex product, which allows for modular product design, resulting in flexibility, which

doesn't come at the cost of partners and results in less stock. Company A has a more complex product which gives restrictions in flexibility. This results in more customer-specific stock. To overcome problems, labelling and classifying orders helps to ensure better communication with customers. Sometimes this leads to suggesting substitute products which help standardization of the customer specific choices, which comes at cost of the flexibility of the customer.

Production flexibility

Production flexibility is the ability to align, adapt and adjust the process of the goods flow including the inbound and outbound activities and the storage of the goods to the changing customers' needs (Hock Soon & Mohamed Udin, 2011) A method discussed in the WC to create production flexibility is through the *availability of different energy sources,* having different energy supplies allows operational activities to be maintained under different circumstances such as energy shortages or cost fluctuations. Also, difficulties in building production flexibility raised during the WC. One participant stated: *"For us, having different energy supplies is difficult because of the additional costs that arise when trying to switch between energy suppliers. Also, green energy options are unstable".* Another difficulty with production flexibility raised: *"We have difficulties becoming flexible because our company is very much influenced by seasonal demand. This is because of seasonal climate changes mainly".* These comments reflect the complexities involved in adjusting production processes and energy sources, which are exacerbated by external factors like climate and energy market stability.

During expert interviews, these difficulties were recognized. Company A mentions a surge in demand in Q4 and highlight the following method to promote production flexibility with seasonal flexibility *"To compensate for the peak in demand, we can move part of the production to Q3 and allow more finished stock".* Also mentioned is the hinder they find while doing this: *"We can only do this for a few months, because we deal with products with a defined shelf life. This is the maximum we can move production".* This further denotes that industry and product complexity influence the capability of being flexible. Company A mentions another option to catch the surge in demand: *"Another possibility is to work together with other parties, who can help you fulfill increased customer demand. This is not something we do or aim to do but is a fallback scenario".* In this case, outsourcing is used to create temporary extra capacity. This means that production does not have to be moved in a timeframe, which also makes it a suitable product for organizations who are restricted with the moment of production. Company B denotes demand surges due to seasonal fluctuations are not seen often, but due to other

circumstances customer demand can surge. They denote the importance of a healthy order book: *"What we do is want to keep a healthy order-book, where you have a minimum number of orders necessary, and then you can play around with pulling orders forward or push back orders. You don't want your order book to be too big because your lead time will be too big, and too short gives you less flexibility. You must play around".* A direct implementation company B has done is to shorten the cycle of production planning: "*By doing this, we got more opportunities to play with orders because the horizon is less fixed, which makes you more flexible. But it also means it requires more flexibility from suppliers and some of the buffers that you have, for which we keep the buffers for critical stock."* Because of a less fixed horizon, company B enables flexibility to change their production schedule but comes at cost of a less certain demand pattern for their suppliers. To be able to employ this method to create production flexibility, company B determines critical stock. Critical stock is defined by company B as follows: *'Critical parts are determined based on uniqueness of the product and supplier performance. If supplier performance is quite low and there are no other products to be sourced, than we will try to get enough stock'.*

Company C operates within the food industry and is heavily influenced by seasonal fluctuations. Product innovation is used to extend the shelf life of the product and increase production flexibility: *"A strategy we have, is to use process innovation to refine our raw product to a different form, in which it is easier to store and has a longer shelf time. In this form, we can refine it later in the year when the peak period is over. In this way we can use our factory a total of 6 months instead of 4, which helps us decrease max capacity of the factory".* Due to surges in demand, the ability to maintain product flexibility is seen as difficult. Moving capacity is mentioned to catch this excess in demand, which can be done internally but also external by outsourcing. Company B mentions that introducing critical stock in which a buffer is made, helps with catching demand surges, as this is hard to source stock, which can be supplemented with easier sourced stock.

Zooming out on the results, production flexibility faces significant challenges due to factors as energy supply instability, seasonal demand fluctuations and product complexity, which can be linked to product shelf-life constraints. Companies often struggle with the costs and instability linked in having multiple energy options, as well as the difficulty of managing production during peak demands periods. Also seen here, product complexity seems to influence flexibility, as production schedules are stricter when operating in complex industries such as the food industry. More flexibility can be found by outsourcing production or moving production to another date but is not always possible. Looking for more internal flexibility by

optimizing products as done by Company C can be seen as a solution to deal with this constraint.

Logistics flexibility

Logistics flexibility is defined as: “the ability to align, adapt and adjust the process of the goods flow including the inbound and outbound activities and the storage of the goods to the changing customers’ needs” (Hock Soon & Mohamed Udin, 2011). WC participants mentioned the method of *combining transportation with partners* enhances the adaptability of the flow of goods by leveraging partnerships to combine transport and create another form of modality, together with partners. This method enables faster replenishing, as fill grade and the costs that account to it, are less of an issue, resulting to more logistics flexibility. But, this was also hindered by the nature of the products and regulatory requirements. One participant explained, *"The products we manufacture don’t allow us to have different transport modalities. We work with products that have strict safety regulations. Therefore, it is not possible to easily switch to a partner that is not known with the intricacies of our products."* This quote underscores the difficulty in changing logistics partners or methods due to stringent safety standards and product-specific knowledge requirements.

Enhancing logistics flexibility was seen as a challenge, especially when complex products and procedures play a role. Company A mentions that they work with an exclusive partner: *"For our export within [location] we are working with an exclusive partner. If this partner can't deliver, we are able to contact another carrier. And outside [location] we have selected a partner on the criteria of region, which is not necessarily the cheapest"* Having an exclusive partner helps to have a partner that knows the intricacies of your product but leaves less flexibility. Company A furthermore mentions: *"For some exports, specialized documentation is necessary, this we arrange with an export partner, who forwards it to the carrier."* Here, the complexity aspect of logistics is dealt with by a third party, which leaves more flexibility in using different carriers, but also transport modalities. Company B notes that they deal with logistic complexity: '*"Normal goods are all on pallets. But what we do is bring in our products just-in-sequence. To be able to do this, suppliers know our production process and already, and the products on the pallets are already in the right order so that the pallet can go straight to the line. Either these parts come from the same supplier, or we cross-dock internally to get the products in sequence".* In this example, the products are not complex, leaving space for optimizations such as deliveries in sequence. Company C mentions their product is not complex, but rather focus speed, therefor, they work with many different carriers

for the delivery of sources: *"On the sourcing side, we work with many local contractors that drive for us. There is flexibility in choosing which carrier will drive for us, but they are mostly local based, close to our suppliers."* Having a lot of options offers flexibility in choosing which carrier to choose from. On the export side, company C mentions: *"Delivering our end products to the customers is done by a select number of carriers, but we can adapt to the needs of the customers. For instance, change to train"* In this situation, different modalities are available resulting to more logistics flexibility.

Broadening the perspective on logistics flexibility, it can be noted that product complexity has a certain influence in the possibility of creating logistic flexibility. Noting that with less complex products, there is more opportunity to have simpler processes and therefor more flexibility. Logistics flexibility seemed to not be the main bottleneck in creating flexibility, as there were a lot of suppliers of transport as noted by the respondents.

Suppliers' flexibility

Suppliers' flexibility is the ability of a manufacturing firm to swiftly and efficiently adapt their operations to meet a manufacturer's condition for components, and by doing this fulfilling the end customers' demand (Swafford et al., 2006) A method contributing to suppliers' flexibility was noted during the WC, and is the method to *introduce preferred supplier programs*. Including suppliers in such programs enhances better relationships with key-suppliers, resulting in better alignment of operational standards, and better adaptability to late changes within customer demand. *Flexible purchase contracts* were also mentioned and allows organizations to adjust order quantities and delivery schedules based on changing conditions. This feature helps manufacturing organizations to adapt their operations to meet end demand, which is particularly helpful if the end-demand is volatile. Communication issues and long-term contract management were identified as barriers to suppliers' flexibility. A participant noted, *"Difficulties in communication, resulting to less flexibility. Because of one contact person who is not high-up in the company, we have less communicative power, and thus a less competitive position for flexibility in the supply of our goods."* Another pointed out, *"Flexible supply contracts are difficult to maintain in the long run. Costs are higher, and you lose margin compared to other competitors. Essentially your business is losing competitive advantage."* These insights highlight the impact of organizational structure and the economic implications of maintaining flexible supply arrangements.

Company A mentions their decision to select a flexible or fixed volume contract is based on customer demand, *"Our preference in contract is based on the forecasts the customer gives us. If the customer gives reliable forecasts, we choose a volume agreement and source products from there. But sometimes the customer is not taking the forecasted amount, and then we're left with a contract to our supplier in which we didn't fulfill the contract, which costs us money"*. The problem that occurs here has to do with inaccurate forecasting, leading to higher costs for company A. To combat having wasted stock, company A is developing a classification: *"We are still developing our ABC classification. Products that are important to us you want more firmness in the contract than for smaller customer specific products"*. Company B denotes that for working with suppliers for transportation, they work solely with flexible contracts within Europe: *'"For carriers, we work with flexible contracts within Europe, in which the volumes can change, which is somewhat the standard, but outside of Europe we work with fixed contracts. This is because we have less power and there are only a few players, so we must adapt to their operations"* Company C only works with fixed contracts with suppliers, because they need to know how much they should supply before they produce: *"We have fixed contracts with all our suppliers, because they need to know how much they should supply beforehand. Therefore, we communicate an amount we need from them. Suppliers get a fixed price for this amount, if they under-perform, we eventually must discuss a solution, if they overshoot, they will get a worse rate for the products above the threshold. If we end up sourcing too much and overproduce, we always have flexibility because we have access to the worldwide commodity market"*.

Having bad communication with suppliers, also due to weak influential power, can lead to less flexibility. Company A also experiences this: *"Sometimes communication issues happen. First you try yourself to fix it, but if that doesn't help, you escalate. There are steps in this, and in the end the CEO of Commercial director can get involved"* Company A has a reactive approach in handling this problem, and don't proactively plan for spotting weak influential relations: *"We do supplier evaluations but are not specifically checking on how influential our contact person is within the supplier firm"*. Company B have a similar reactive approach to this but aim to be more collaborative in helping suppliers if problems occur: *"Some suppliers you are 80% of their turnover, and others 0.8%, this leads to different ways of doing business. We have a very strong quality team that can fly over to our suppliers and help them with their problems, and make sure that we get out products. To turn to this solution, we have an escalation model. If you haven't delivered what we've asked, you get a call, and if it doesn't work, then we go in escalation mode. If this means we must fly there to help you and that we*

get our products, that is possible'. In both examples, power and force is the main aspect to reach organizational goals, instead of a collaborative proactive approach. Company C notes: *"Because we work with fixed contracts which the supplier has agreed on, we don't have a lot of communication issues. This is also because our supplier only supplies to us, we work together, we have common interest.".*

Looking at shared characteristics for the dimension suppliers' flexibility, a certain cooperative aspect of supplier relationships is neglected. The focus for organizations is on profitability of their own firm by contract management and utilizing power, instead of having a holistic network view, and cooperating with partners across different nodes to create flexibility.

Supply base flexibility

Supply base flexibility is the ability of a firm to modify its buyer-supplier relationships without incurring significant penalties in terms of cost, time, and effort (Gosain et al., 2004). Participants of the WC discussed *Dual sourcing* as a method to create supply base flexibility. Dual sourcing involves having two suppliers for a certain component, which mitigates risk and ensures continuity of supply. This method enhances supply base flexibility, as it allows the manufacturing firm to switch to a different supplier without significant penalties in cost, time, and effort. Dual sourcing practices faced several challenges, from quality control to compliance and resource allocation during disruptions. One participant shared, *"We considered dual sourcing for our strategic products, but unfortunately, we see that our demand asks for a certain quality that our second supplier can't deliver. Therefore, dual sourcing is hard and intensive. Because our operations and customer demand do not allow us to have a B-tier quality product."* Another participant added, *"Dual sourcing will be more difficult for us because we see an increase in compliance with CSRD and CSDD. If we would proceed with dual sourcing, we would have twice as many suppliers to keep an eye on regarding these rules and compliance."* Furthermore, a participant observed, *"We used dual sourcing in the past but noticed that in case of using this dual source, our power was very limited due to our relationship with them. Therefore, the dual source was irrelevant because if there would be a supply chain disruption, we wouldn't be able to acquire resources."* Finally, it was mentioned: *"Within dual sourcing, we saw that when a certain disruption happens, there was no assurance these agreements would hold when a disruption was happening. Preferred suppliers would get the most resources allocated, whilst we as a smaller party wouldn't get our supplies".* These

quotes illustrate the intricate balance between maintaining supply quality, adhering to compliance standards, and ensuring resource availability during disruptions.

Dual sourcing was noted as a strategy to enable supply base flexibility, but also raised problems among organizations. More specifically, a problem that raised was that dual sources could not always deliver the quality that the end consumer was asking for, which made dual sourcing less feasible. Company A experiences this challenge, as they are working with complex customer specific products. At the moment, they don't have dual sources incorporated in their operations, because the nature of their products do not allow this. But they do have a proactive approach: *"In a sense we have organized dual sourcing, because we have mapped them. But is not integrated in our production process."* The complexity of the products limits the option of dual sourcing, but company A did try to find the closest way to a dual source. Furthermore, company A mentions: *"If a disruption happens, I am not sure if we can adapt to these suppliers, but you have to experience when it happens".* Dual sourcing is more a conceptual methodology for company A. Company B mentions dual sourcing as well as local sourcing as a strategy: "*Yes we definitely use dual sourcing, we have production sites around the world and try to source as many local parts as possible. You would say you become inflexible because of that, but because of our modular products, we make the same products everywhere across the world, and it gives flexibility, because if we one supplier falls away, we always have another one somewhere. "* Complexity of products does not work well with having dual sourcing options. When asking company B how they deal with this if they must source technical products, they mention: *"Sometimes we encounter difficulties finding a second source, for instance when the product is very complex. We are a company that goes in cooperation mode. So, for example, when a company can't make our product yet, we can help them in finding a way for them to develop it. Instead of settling for a "no" we continue to ask and find a solution together".* This denotes that complexity of products fully blocks the option for supply base flexibility. Co-operation with smaller suppliers to be able to make specific products for your production facility is an option to try to get a dual source. Not always this is feasible, company B also notes: *"Sometimes it doesn't work out to have a second supplier, and that happens too. You can decide to make it yourself, but that is not possible for every product."*

Concluding, dual sourcing is a strategy to increase supply base flexibility, but organizations experience difficulties when product complexity increases. Although there are still opportunities to incorporate dual sourcing when complexity of products enhances, as mentioned by company B to introduce supplier development.

4.3 Connecting the dots – concluding findings

Within the quantitative results of this study, observed was that organizations in the process and manufacturing industry have significant difficulty building SCF. Looking at the individual items that contribute to SCF, a low score is noted for the item '*Processes and sequence/route of production operations can be easily modified*'. This corresponds with difficulties experienced by practitioners, where product complexity was experienced as a limiting factor in a firm's ability to enhance manufacturing flexibility, consisting of product development flexibility, production flexibility and logistics flexibility. Product modularity is the most effective concept that has been proposed to deal with these challenges. In this sense, one can make independent modifications to some given modules without necessarily changing the whole product. Such independence makes it much simpler to change the production operation as and when need be. Moreover, with production based on interchangeable modules, firms can more easily switch the sequence of operations to match new requirements, to get the best possible efficiency, or to respond to unanticipated challenges. Apart from this, modularity enhances the overall scalability and adaptability of the process of production, allowing firms to easily introduce new technologies or processes in the individual modules without the complete redesign of the production system. Therefore, the introduction of product modularity not only eliminates the issues associated with product complexity but also enhances the general manufacturing flexibility.

However, when modularity is not feasible either because of a product's nature or due to the industry of operation, there are other strategies which have to be applied. In such a situation, effective communication with suppliers and stakeholders is essential in identifying and implementing solutions that can help cut the number of stock-keeping units. When SKUs are consolidated, it eases the inventory management and, by extension, the supply chain. This creates a more linear and predictable supply chain because the lesser variety in SKUs will translate to reduced complexity in production planning, procurement, and distribution. This will enable easier adaptation of production and inventory to demand, which can lead to increased forecast accuracy, reduced lead times, and the possibility of cutting costs. So even without modular products, collaborative efforts with suppliers and stakeholders can significantly enhance the efficiency and responsiveness of the supply chain.

Furthermore, network flexibility is observed as a neglected aspect within SCF. As noted within the WC, focal firms tend to switch to a power-based approach within suppliers' flexibility dimension. The same approach was observed within expert interviews, where the

focus was on competitive position rather than on a collaborative approach to create flexibility throughout the chain. A method to create supply base flexibility is to incorporate dual sourcing. Product complexity enhances difficulty to find second suppliers for certain products, as production facilities can be set-up specifically for one source. Incorporating product modularity can also help to find a dual source, because firms can in turn simplify the production process and make it more adaptable to multiple suppliers.

5. Conclusion

The goal of this research is to empirically contribute to existing literature on the topic of SCRES (Ali et al., 2017). It aims to do so with a mixed-method research approach, to ensure the most relevant contribution. In this research, six different research sub-questions were conceptualized, which will be answered in this concluding section. Furthermore, a concluding answer will be given on the main research question.

What supply chain resilience capabilities are described?

In this research, the SCRES capabilities that are conceptualized in previous research by Dinalog (2023) are used. This approach was selected because this thesis is part of a broader research which builds upon the research of Dinalog (2023). The SCRES capabilities that are described are: Redundancy, collaboration, flexibility, visibility and agility. Looking at SCRES capabilities through a social-ecological lens by Wieland and Durach (2021) reveals that the capabilities flexibility and redundancy contribute towards social-ecological resilience, which is argued to be true SCRES (Ali et al., 2017).

How are supply chain resilience capabilities evaluated?

The survey as proposed in the NGR research (Resiliencescan, 2024) has been adapted within this research. This is a survey designed for organizations operating in the process and manufacturing industry, where supply chain capabilities are analyzed for the focal company, but also for the tier -1 and +1 organizations. Each capability is measured on upstream, internal and downstream items on a five-point Likert scale.

What are the outcomes of these evaluations among organizations in the process and manufacturing industry?

Most striking outcomes included the capability flexibility being significantly different evaluated to all the other capabilities, adding to that, it was the lowest scored capability, marking an area of interest. Furthermore, the item within SCF, '*Processes and sequence/route of production operations can be easily modified',* was scored the lowest.

What dimensions of supply chain flexibility are recognized?

The different dimensions of SCF as conceptualized by Jin et al. (2014) are used within this research, because it touches on the network aspect SCRES also bears. In this definition manufacturing flexibility of the focal firm is categorized in three dimensions, product

development flexibility, production flexibility and logistics flexibility. Furthermore, network flexibility is segregated to suppliers' flexibility and supply base flexibility.

What difficulties in supply chain flexibility are experienced by practitioners?

In a WC set-up, difficulties regarding different dimensions of SCF were experienced. Product development flexibility was experienced as a challenge due to organizations handling customer specific products. Also, complexity of products made it more difficult to achieve product development flexibility. Difficulties regarding production flexibility entailed dealing with seasonal influences, and product complexity, both limiting the opportunity for production flexibility. Logistics flexibility was seen as challenging, as product complexity limited possibilities for organizations to work with multiple carriers that were known with the intricacies of their product. Concluding, the availability of complex and customizable products seemed to have an influence on the possibility to create manufacturing flexibility.

Network flexibility consists of suppliers' flexibility and supply base flexibility. Within suppliers' flexibility, problems are observed in communication with suppliers. Also, difficulties in handling flexible contracts while staying competitive. Suppliers' flexibility is observed to be an overlooked dimension in SCF, with practitioners focusing more on their own firm's benefits rather than a collaborative perspective. Supply base flexibility was observed to be a difficulty in building SCF, especially when an organization is working with complex products. High product complexity increases dependence on current suppliers and raises the barrier to finding alternative suppliers willing to collaborate, resulting in lower supplier' flexibility.

How do organizations overcome difficulties in building supply chain flexibility?

Product modularity was given as a method to overcome limited flexibility in product development. Outsourcing, or upfront production were methods to overcome difficulties in production flexibility, where product complexity had a limiting factor on upfront production. Product optimization also helps with building difficulties in logistic flexibility, as this enables barriers for potential carriers to help you and build flexibility. Supplier' flexibility can be created by operating in flexible contracts and preferred supplier programs, also, having back-up markets available can work in some cases. To overcome problems in building supply base flexibility, product modularity can help to decrease the number of SKUs that are needed, therefor increasing buyer power, and the possibility to have multiple suppliers. When working

with a complex product, supplier development is another possibility to overcome difficulties in supply base flexibility.

What strategies can organizations implement to overcome the biggest difficulties in building supply chain resilience capabilities?

As can be seen from both quantitative and qualitative results, biggest difficulties in building SCRES capabilities commence with building SCF. More specifically the item, *Processes and sequence/route of production operations can be easily modified'* was scored as the lowest item in the realm of SCF. Looking at the interviews, this problem was also touched upon by practitioners, where product complexity was seen as one of the biggest limiting factors for reaching SCF. A strategy to overcome the biggest difficulty, was given in product design optimization, more specifically in introducing product modularity. By doing this, independent modifications can be done to modules without changing the product, which contributes to make it simpler to change production operations. Contributing to the following dimensions of SCF, product development flexibility, production flexibility, logistics flexibility and supply base flexibility.

6. Discussion

Building upon the conclusions presented in the previous chapter, this section will explore both academic and practical implications of the research findings. Additionally, the limitations of this study will be addressed, along with suggestions for future research to enhance and expand upon the current work.

6.1 Theoretical contributions

This research makes multiple theoretical contributions to the realm of SCRES. Firstly, 85 manufacturing organizations are quantitatively assessed, an assessment of firms on this scale was not found in literature before. Furthermore, these are assessed on a multi-tier level, which is seen as the next step in exploring the construct SCRES (Wieland & Durach, 2018). Usage of a multi-tier SCRES assessment builds upon the foundation constructed by Pettit et al. (2019) in assessing SCRES quantitatively. This is in line with calls to transplant ecological and holistic thinking into management principles (Ergene et al., 2021). The different results on the capabilities of SCRES were examined, and SCF was found as a difficulty for organizations in the process and manufacturing industry. This paper examines the different difficulties and methods to build SCF in a SCRES context, which is an empirical contribution to the current literature on SCRES (Ali et al., 2017).

6.2 Practical implications

This research makes practical implications for organizations operating in the process and manufacturing industry. First, a suggested area for organizations to look at when trying to build SCRES is SCF. In this study, distinct challenges and methods are described that practitioners can recognize and use as a first step in creating a flexible supply chain. What also can be noted from this study is that there is no one-size-fits-all methodology to build SCRES. Organizations should use their own context to view possibilities and become resilient. This also holds value for organizing SCF, in which industry characteristics and product complexity can have a limiting effect on the possibility of building SCF. Nonetheless, a practical implication can be found in implementing optimizing product design, more specifically, in modular product design. Firms should critically assess their own products, and try to make these modular, or if not possible, simplify them. By doing this, it is possible to create SCF whilst keeping the actionable operation of transforming the product internally.

6.3 Limitations

Within the quantitative part of this study, one main limitation was the usage of a pre-determined survey, which was used without having the opportunity to amend it. This research is part of the project 'Next Gen Resilience', which meant this survey was the framework in which the study had to be operated. This led to working with a set of capabilities and items that could not be judged by the researcher. A second limitation is that within the literature review the construct SCF was operationalized using literature from a relatively long time ago. There could be a mismatch between the definitions then and now, especially seen the rapid advancements made in SCF and SCRES literature. Another limitation of this research is the focus on SCF from the viewpoint of the focal firm. Due to limited time available for this research, singular nodes were assessed during the qualitative part of the research, neglecting the dynamism and complexity of supply chains (Wieland & Durach, 2018). The WC that was conducted differed from the guidelines as written by Schiele et al. (2022). First of all, the discussion rounds that took place were shorter in time than the advised amount of time, resulting in less variated results. Furthermore, there was no revalidation moment in place, resulting in a lower validity of the methodology. Also, the discussion groups were of bigger size, which led to less intimate discussion rounds. Another limitation is the limited sample size in the expert interview methodology. Three manufacturing firms were assessed in interviews regarding methods in overcoming difficulties in building SCF, this is very short, as basic themes in qualitative data start to emerge as early as 6 interviews (Guest et al., 2006). Furthermore, generalizability is also limited as the characteristics and industry of the assessed organizations during the interviews were not identical. Therefore, it is inappropriate to suggest the results from the expert interviews are transferrable to an average manufacturing firm. Noting these limitations, the results are still valuable insights into specific cases and serve as a foundation for further developments in the field of SCRES and SCF.

6.4 Future research

- The survey that was used in this research should be revalidated to check if all questions are relevant to the definition of multiple tier SCRES research.
- Future research should use a bigger sample size for the NGR scan, to validate if existing questions are relevant to the different SCRES capabilities. A critical examination of reliability and validity of the scan is necessary.

- The multi-tier aspect of the NGR should be critically assessed, contributing to construct and content validity of the NGR scan.
- To align SCRES research with the dynamism of supply chains, an option for future research is to focus solely on a singular capability of SCRES within all tiers of supply chains. By doing this, a more complete overview of interactions within multiple nodes of a supply chain can be assessed.
- An exploratory relation of product complexity was examined on the possibility of a firm to adapt to SCF. Future research should examine this relationship further and look for possible typologies of levels and complexity and opportunity to build SCF.
- The different effects of product modularity on SCF should be further researched. More specifically, what are the specific effects of product modularity on the different dimensions of SCF?

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Appendix A: Survey operationalisation

Capability	Code	Upstream	Internal	Downstream
Redundancy	R1a	Multiple / backup suppliers available for all components	Multiple / backup production lines in multiple production location	Short-term alternative markets available
	R1b	Suppliers are geographically dispersed	Production locations are geographically dispersed	Customers are geographically dispersed
	R1c	Suppliers do not have the same sub supplier for critical parts/ingredients	N/A	Short-term alternative customers available
	R2	Suppliers guarantee to keep extra buffer stock (for several weeks)	Extra buffer stock (for several weeks)	Customers hold extra buffer stocks (for several weeks)
	R3	Multiple transport modes possible	Multiple DCs distributed geographically	Multiple transport modes for distribution to customers possible
	R4	Suppliers guarantee to keep extra capacity available (>50% of normal order volume)	Additional production capacity (+50%) available	Contracts offer the possibility to deliver 50% more or less
	R5	Suppliers have sufficient financial buffers	Sufficient financial buffers (minimum 6 months)	Customers have financial buffers (for at least 6 months) or credit insurance available
Collaboration	C1a	Investments have been made in a long-term relationship with a lot of openness and trust	Problems are solved by multifunctional teams	Investments have been made in a long-term relationship with a lot of openness and trust
	C1b	Problems are solved by joint teams	Goals and KPIs are clear and cross-departmental	Problems are solved by joint teams
	C1c	Potential disruptions in the chain are communicated in a timely manner	Culture of continuous learning and improvement	Potential disruptions in the chain are communicated in a timely manner

	C2	Schedules/forecasts are made together with suppliers (minimum monthly)	S&OP/IBP process functions well and is mature. Board member and operations, finance and logistics are present. Department plans are coordinated	Joint planning (including promotions) and forecasting (minimum monthly)
	C3	Business continuity plans are created, tested and evaluated together with suppliers	Every employee is aware and involved in safety and risk management. Business continuity plans are current and regularly tested	Business continuity plans are created, tested and evaluated together with customers
	C4	Supplier and buyer both influence payment terms or supply chain finance solutions are used voluntarily	Financial planning is an integral part of S&OP/IBP (volumes are translated into value)	Supplier and buyer both influence payment terms or supply chain finance solutions are used voluntarily
Flexibility	F1a	Contractual agreements that volumes and/or timing may deviate significantly in the short term	Employees and production resources can be used for many different types of products (multi-purpose)	Flexibility in contracts/agreements to adjust prices, quantities and timing/location
	F1b	N/A	Capacity can be easily increased/decreased	Flexibility in contracts/agreements to adjust prices, quantities and timing/location
	F1c	N/A	Production can easily be moved to another location	Multiple (sales) channels available
	F2a	Components/raw materials can easily be replaced by alternatives	Components are used in multiple products	Customers accept customization/substitution of products
	F2b	Packaging materials can easily be replaced by alternatives	Products can be easily adapted/redesigned	N/A

	F3a	Alternative transportation options, alternative suppliers available	Processes and sequence/route of production operations can be easily modified	Alternative modalities / transport lanes possible. Transport network can be easily adapted
	F3b	Circular alternatives (recycling, refurbishing, etc.) available	N/A	Flexible order fulfillment possible
	F4	Flexibility in INCO terms, payment terms, etc.	Alternative sources of financing available	Flexibility in payment terms, supply chain finance available
Transparency	V1a	Major suppliers share production planning for at least the next 4 weeks	Reliable and current data of all key processes is available where necessary in the organization. There is real-time insight into current stock positions and production plans	Forecasting is good and based on end consumer demand
	V1b	There is a good view of the supplier market (availability of alternative suppliers, price development, etc.)	The management is based on KPIs that are aligned throughout the organization and current values are visible for all departments	Stock positions and demand (POS) data is shared in real time, as well as forecast and campaign/event planning (promotions) of customers
	V1c	N/A	With changes in the planning, the impact on costs, service and sustainability is transparent	Market trends, competition and potential customers are transparent
	V2a	Order and invoice flows fully automated and integrated with key suppliers	Datawarehouse/datalake is available with all relevant data	Order and invoice flows fully automated and integrated with key customers
	V2b	Critical suppliers share tracking & tracing info	Decisions regarding operation, maintenance and logistics are supported by	Tracking & tracing information of shipped products is shared

			accurate and up-to-date data and models	
	V2c	There are agreements with suppliers that disruptions in the chain are reported immediately	There are enough qualified employees who can create dashboards and perform analyses	N/A
	V3a	There is good insight into who tier 2+ suppliers are and their location, how transport lanes run and what possible problems/risks are (supply chain mapping)	All relevant risks have been identified and a business continuity plan is in place, up to date and tested	Early identification of problems/disruptions in all markets/customers. Agreement with customers that (potential) disruptions are reported immediately
	V3b	Periodic audits at key suppliers (including cyber security audit)	Cybersecurity is a top priority. Recovery plans are up-to-date and regularly tested	N/A
	V4	Up-to-date and reliable insight into creditworthiness/financial health of suppliers	Real-time insight into credit limits and financial flows and key metrics. Processes are unambiguous, transparent and responsibilities clearly defined	Up-to-date and reliable insight into creditworthiness/financial health of customers
Agility	A1a	Frequent and fast replenishment	Short lead times	Fast and frequent restocking of customers
	A1b	Efficient order process	Continuous improvement program to reduce lead times, changeover times (SMED) and decrease batch sizes	New products can be brought to market quickly (NPI)
	A1c	Onboarding new suppliers can be done quickly	N/A	Fast and efficient process to onboard new customers
	A1d	Contracts can be adjusted at short notice	N/A	N/A

	A2a	Contracts offer the possibility to adjust volumes, location and times in the short term	Frozen period is short, short and frequent production runs	Inventories can be moved quickly between regions/DCs
	A2b	Change in transport mode available and express transport options available	Processes are constantly being improved and can be adapted quickly	Short-term change in transport mode possible and speed transport options available
	A3a	Short lines of communication with suppliers and fast decision-making	Short lines of communication and fast decision-making. In an emergency, decision-making procedures can be quickly adapted (additional mandate if necessary)	Short lines of communication with customers and fast decision-making. In case of shortages, allocation rules are known and can be implemented quickly
	A3b	N/A	Strategies and new business models can be implemented quickly	N/A
	A4	Efficient Purchase-to-pay process (best in the industry). Days Payable Outstanding (DPO) low. Quick onboarding of supply chain finance solution	Short Cash-to-cash cycle, Days Inventory Outstanding (DIO) low	Efficient Order-to-cash process (best in the industry). Days Sales Outstanding (DSO) low. Quick onboarding of supply chain finance solution

Appendix B: Interview guide

RQ:*"What strategies and best practices can organizations implement to overcome difficulties in building supply chain flexibility, to enhance overall supply chain resilience?"*

Introduction / warm-up

1. *Introducing the research and setting the stage.*

- Introduction of the researcher.
- Explain the purpose of the research.
- Elaborate on the objective of the interview, how it fits in the research.
- Denoting confidentiality. Asking for permission to record the interview.

2. *Getting to know the interviewee*

- What is your current function and responsibilities?
- What responsibilities are attached to this?
- What educational/professional background do you have?

Interview questions

1. *Product development flexibility*

- Does your organization work with customers that require customer-specific products? If so, how does your company manage to be flexible to meet this changing customer demand?
- What processes or technologies help in adapting to customer-specific requirements?

2. *Production flexibility*

- Seasonal demand fluctuations have been noted as a significant challenge in building supply chain flexibility. How does your company manage these fluctuations?
    - What strategies or practices have been effective in your experience?
- Balancing operational efficiency with flexibility is crucial. How does your company ensure that machinery and production processes remain flexible, especially during peak production periods?"
    - Follow-up: "What specific practices or technologies have you implemented to achieve this balance?
- Flexible supply contracts are difficult to maintain due to higher costs and potential margin losses. How does your company handle flexible contracts while staying competitive?

    - Are there any innovative contract structures or negotiation techniques you use?

3. *Logistics flexibility*

- Are there products that need a special logistic/transportation approach? How does your organization manage flexibility with these products?
    - Have you developed partnerships or protocols that help overcome these logistic challenges?

4. *Supplier flexibility*

- One of the challenges identified is difficulties in communication, especially when dealing with less influential contacts within supplier companies. How has your organization addressed this issue to enhance flexibility in your supply chain?
    - Can you provide specific examples or strategies that have worked well?

5. *Supply base flexibility*

- Switching between different energy supplies and managing associated costs is another challenge. How has your organization approached this issue?
    - Have you found any reliable solutions or partnerships that help stabilize energy supply options?
- Dual sourcing has been identified as both a potential solution and a challenge. How has your organization managed dual sourcing to ensure quality and compliance required?
    - Can you share examples of successful dual sourcing strategies you've encountered?

Closing

- Summary of the discussed topic.
- Do you have any questions or comments about this interview?
- Thank the participant for their time.