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Digital Technology in SCRM

A Qualitative and Exploratory Study on how Digital Technology can Improve SCRM

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A project submitted to Université Catholique de Louvain (UCL) – Louvain School of Management – and the Norwegian School of Economics (NHH), in partial fulfilment of the requirements for the degrees of Master in Business Engineering at UCL and Master in Economics and Business Administration at NHH. Please note that neither the institutions nor the examiners are responsible − through the approval of this thesis − for the theories and methods used, or results and conclusions drawn in this work.

Contents

List of Figures

List of Tables

Declaration on the use of AI tools in the work on this master's thesis

Name (and version) of the AI tool: ChatGPT versions 3.5, 4.0, and 4o.

Purpose of using the tool: ChatGPT was used to summarize articles, for ideation, and for finding weaknesses in my own work. In preparation for the interviews, ChatGPT was used to write and finetune the interview questions. During the data analysis phase, it was sometimes used to find suitable codes for hard and ambiguous units of data, but also to categorize codes into themes. The suggested themes were often off-target, but they nevertheless provided insights and inspiration, as well as helped in cutting down and merging codes. All interviews were conducted in Norwegian, and while writing the results chapter, it translated the verbatims to English. The translations were, however, reviewed to ensure the sentences maintained the same meaning.

I am aware that I am responsible for all content of this master's thesis, including the parts where AI tools are used. I am responsible for ensuring that the thesis complies with ethical rules for privacy and publication.

Preface

This thesis has been part of the Double Degree program between Université Catholique De Louvain/Louvain School of Management (UCL/LSM) in Belgium and the Norwegian School of Economics (NHH) in Norway, in partial fulfilment of the requirements for the degrees of Master in Business Engineering at UCL and Master in Economics and Business Administration at NHH. This work was conducted over two semesters (February 2024 to December 2024).

This thesis started out as an attempt at combining several macrotrends affecting companies and economies today, namely digitalization, increasing risk levels, and an increased focus on supply chains. By shedding light on this intersection, I hope to enlighten companies in a time characterized by shifts and changes and to provide insights on how companies may leverage the new opportunities while avoiding the threats and challenges. The interest in the topic among my respondents underlines its relevance within various industries. In the early phases of the thesis, a sustainability perspective was considered but had to be abandoned due to a lack of suitable respondents on the topic. This led to a shift in the focus of the thesis and a delay of several months, making it necessary to extend the process by one additional semester.

Working with this thesis has taught me about the complex networks needed to create and deliver the things we take as granted in our daily lives, but also how fragile these systems are. I have also learned how digital technologies can be leveraged to ensure our daily access to for example toilet paper or milk. Lastly, I must also admit that this project taught me about the laborious process of knowledge creation, but that it added to my motivation for pursuing a PhD later.

Grenoble, France

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Writing the thesis has been a dauting task ending up taking more time than expected. Parallel to this project, I have also been a full-time student at a third university. Finally at the finish line, I want to thank all the people who helped and supported me through this process.

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My family must also be thanked for answering late night calls and messages when the thesis took sudden and unexpected turns, things were delayed, or when I needed emotional support, motivation to continue, or a way to let out my anger and frustration.

My seven respondents were crucial for the completion of this thesis. Thank you for giving of your time and sharing your insights with me. For you knowledge on the topic, and your sincere interest in providing me with the information I needed, you have my admiration and respect.

This thesis has been a collaboration between two universities in two different countries, and the writing process was conducted in a total of seven countries. Through these experiences, I have made friends from all around the world. These encounters have taught me that cultural differences and language barriers can be overcome through mutual efforts. I believe the same holds true for global supply chains and the increased risk levels. Through collaborative actions and mutually beneficial relationships, the world can unite and even the hardest problems solved.

Abstract

Purpose: The purpose of this study is to examine how digital tools and systems can improve supply chain risk management (SCRM) in companies. This is an underdeveloped area in the literature, but one of high importance due to rising risk levels caused by increasing geopolitical tension, high inflation, climate change, and wars breaking out close to critical trade routes. Rather than focusing on specific tools, this thesis aims at providing a holistic understanding on how digital technologies fit within the area of SCRM.

Methodology: This study is mainly explorative, but with hints of descriptive and explanatory aspects. It is inductive and qualitative, using heterogeneous data sampling, semi-structured interviews, and thematic analysis to draw conclusions and construct a framework.

Findings: There are three main findings in this thesis. (1) In fully integrated ERM systems, risk identification, analysis, and monitoring merge together. (2) Digital technology can provide a wide range of benefits, including more and better data collection, complex data analyses and decision support, triangulation, and high-quality real-time data. These benefits can in sum provide deeper, better, and more reliable real-time insights on a larger part of the business environment, thereby enabling early-stage risk identification and more targeted risk mitigation. (3) Through constant monitoring of risk levels, the effectiveness of risk mitigation strategies can be indirectly assessed. If the risk levels remain high over time despite mitigation efforts, it indicates ineffective mitigation strategies that must be adjusted or replaced. Close monitoring of criticality, and the impact of mitigation strategies, can, over time, improve risk mitigation.

Key contributions: A framework is developed to better explain the relationship between technology and SCRM, taking contextual factors into account. It is a holistic framework applicable within different industry contexts, and provides a starting point for future research.

Key words: risk management process, SCRM, digital technology, framework

1. Introduction

We live in a globalized economy where a product and its components traverse the globe before reaching its end consumers. The consecutive chain of companies, from extraction of raw materials until the shop shelves, is called the supply chain. If any of the links in this chain is interrupted, it can lead to delays, stockouts, and non-deliveries. For consumers, it means they do not get their products on time. For companies, it can mean lost sales, increased costs, or damages to their reputation. It is therefore in the interest of all involved parties that the chain works. However, "*a supply chain is as strong as the most vulnerable member of the supply chain*", and the probability of risks materializing grows as a function of supply chain length (Gurtu & Johny, 2021). Supply Chain Risk Management (SCRM) is the conduct of managing and minimizing the impact and probability of such disruptions in the supply chain.

International supply chains are becoming more complex, with greater uncertainties, shorter product and technology life cycles, and more manufacturing (Zimon & Madzik, 2020). At the same time, we live in a world in constant change and have during the last few years witnessed a global pandemic, several wars, high inflation, increasing costs for raw materials, and climate change (Kamakela et al., 2023). Consequently, risk levels have increased internationally, and when materialized, these risks can have fatal consequences for both the production, distribution, and delivery of goods in the supply chain. The complex relationships between supply chain partners, combined with market changes, makes it hard to identify and monitor risks, emphasizing the role of tacit knowledge, experience, and expertise of decision makers (Villanueva et al., 2022). Additionally, costs, dependencies, and the potential risk of revealing secrets to competitors makes it hard to coordinate supply chain risk management (SCRM) across the supply chain (Fischer-Preßler et al., 2020). With increasing risk levels, risk management is however inevitable to ensure smooth operations.

Areas of research for operational risks are unspecific and tend to concentrate predominantly on internal risk factors (Fischer-Preßler et al., 2020). The shift in research focus towards supply chain disruptions, supply chain resilience, and supply chain robustness after the Covid-19 outbreak stands as proof of the knowledge gap within this domain (Dohale et al., 2023; El Baz & Ruel, n.d.; Nayal et al., 2022; Nikolopoulos et al., 2021). New solutions are needed to improve SCRM and to build stable, robust, and resilient supply chains.

In this regard, we consider another macrotrend affecting global markets – namely, digitalization and the rise of digital technology. Numerous kinds of technologies exist, including software and IT solutions. Creazza et al. (2022) found that if one company in the supply chain has limited technology and risk management, it causes vulnerabilities to the entire supply chain, both upstream and downstream. In other words, risk and uncertainty are transferred between companies and propagate through the supply chain. Likewise, El Baz & Ruel (n.d.) found the risk management of different supply chain actors to be closely related. SCRM should, therefore, be conducted as a collaborative effort among all supply chain parties to achieve the maximum result possible from each individual firm's contributions.

Academia has discovered multiple ways in which technology can benefit SCRM, and the focus on IT systems has shifted from ERP systems to novel applications like big data analytics, business intelligence tools, cloud computing, and mobile applications (Fischer-Preßler et al., 2020). However, there still exist some important research gaps that must be filled. According to Fischer-Preßler et al. (2020), there is a lack of a unified approach linking information sharing, collaboration, and other capabilities of IT technology to specific parts of SCRM. This, they argued, has led to an absence of research on risk identification, analysis, and monitoring. They also found that research mainly has focused on IT for risk reduction, while insights into other areas of SCRM remain sparse and fragmented. Aboutorab et al. (2021) looked at the effectiveness of different risk identification techniques in modern supply chains and argued that risk identification in companies focused too much on the internal factors, disregarding the impacts of environmental and exogenous risk factors on company processes.

1.1 Developing the Question

Considering the changes in international markets, increasing risk levels, and the growing importance of SCRM withing the context of the digitalization megatrend, we may wonder to what extent technology could benefit SCRM processes more holistically. Taking all these trends and factors into account, we end up with the research question of this thesis:

How can the use of digital technologies improve supply chain risk management?

1.2 Methodology

This thesis is an explorative qualitative study aimed at inductively developing a framework to better explain the relationships between different kinds of technology and how these can improve SCRM activities. By utilising a heterogenous sampling technique, the goal is that the resulting framework and conclusions can be applied to a larger variety of industries and supply chain structures, rather than confined to a specific context. The data collection was carried out through semi-structured interviews with representatives from six companies, spanning different industries and various roles within their respective supply chains. Thematic analysis was used as the analysis method. For a more thorough elaboration on methodology, see chapter 3.

1.3 The Structure of the Thesis

This thesis is structured into six major parts. First the introduction, which sets the stage for the research. Next is a thorough literature review on the research in this area. The literature review is divided into two sections: one focusing on SCRM and the other on technology. Following the literature review is the methodology chapter, offering an in-depth and detailed explanation of the methodological approach, including theoretical justifications for the choices made. The fourth part presents the findings and the main results of this research, culminating in the proposal of a new framework at the end of the chapter. The fifth part is the discussion chapter, where the findings are discussed in light of prior research. The last chapter concludes the research by addressing the research question, presents the main theoretical and managerial contributions, suggests avenues for further research, and highlight the limitations of the study.

2. Literature Review

2.1 Supply Chain Risk Management

2.1.1 Increasing Complexity in Global Supply Chains

A supply chain consists of links – relationships between adjacent and consecutive parties in the flow of goods, from raw material to final product. The total of links needed to create a product or service constitutes the supply chain (Guo et al., 2017). Links can exist between retailers, manufacturers, remanufacturers, suppliers third party collectors, and consumers (Guo et al., 2017). There is great consensus about international supply chains becoming more complex, with greater uncertainties, shorter product and technology life cycles, and more manufacturing. Additionally, supply chain complexities have increased as companies now reach a larger variety of customers, utilize several channels, and offer a wider range of products (Chand et al., 2018). Customization in the supply chain, companies striving to become a "one-stop shop", mechanization, and a focus on developing agile supply chains further add to the supply chain complexity. Other contributing factors are globalization, technological disruption, market uncertainty, increasing geopolitical risks, and changing laws and regulations (Chand et al., 2018). Complexity leads to uncertainty, and uncertainty leads to disruption. Risks can be hard to predict but may materialize rapidly (Zimon & Madzik, 2020).

Market uncertainty is the most important complexity driver, but demand and supply uncertainties also have a major impact on the performance of the manufacturing function (Chand et al., 2018). According to Bode & Wagner (2015), there is a positive empirical relationship between supply chain disruptions and upstream complexity, meaning higher complexity at the beginning of the supply chain leads to more frequent disruptions. Chand et al. (2018) argues that understanding and managing the drivers behind supply chain complexity would lead to better supply chain performance and customer satisfaction.

2.1.2 Risk

Risks are "*internal and external factors making it uncertain whether or how a company will achieve their objectives*" (Lachapelle & Hundozi, 2015). These uncertainties can have positive, neutral, or negative effects on a company's performance. The effect of the uncertainty on the company is called *risk*. Negative risks, also called downside risks, are the ones considered in

the context of risk management. This was highlighted by the remark of Shenoi et al. (2018) that no single risk improved the firm's performance. Risks differ with regards to their probability and impact (Fjader, 2020). To distinguish risk from *disruption*, risks is the likelihood of something bad happening, whereas disruptions are the materialization of such risks (DuHadway et al., 2019). Disruptions may be directly or indirectly caused by the risks (DuHadway et al., 2019). Then again, *shocks* are considered deviations from the long-term mean (Nikolopoulos et al., 2021). *Uncertain environments* emerge from cyclical business behaviour, demand fluctuations or disasters and lead to supply chain risks (Gurtu & Johny, 2021).

Fischer-Preßler et al. (2020) and Urciuoli & Hintsa (2018) both defined *supply chain risks* as the impact and probability of negative uncertainties capable of disrupting the flow of information, material, or products from suppliers to end users, as well as obstructions to achieving supply chain goals. The interconnectedness of supply chains means that disruptions in one part of the chain can propagate through the chain, consequently causing disruptions at other parts of the supply chain. These can be either upstream – the bullwhip effect, or downstream – the ripple effect (Scarpin et al., 2022). We understand by this that SCRM has a broader scope than ans individual company (Fischer-Preßler et al., 2020).

As we see from table 1, there are several ways of categorizing risks. Distinctions can be made between *endogenous risks*, internal risks that only affect the supply chain, and *exogenous risks* that are part of the external environment (DuHadway et al., 2019; Rauniyar et al., 2023). Endogenous risks have devastating effects on financial performance. Risks can be *intentionally* caused by e.g. maleficent or opportunistic behaviour, or be *unintentional* or *inadvertent* like accidents (DuHadway et al., 2019; Rauniyar et al., 2023). Intentional behaviour, whether it is endogenous or exogenous, is the most impactful as it is designed to cause the most harm or to capture as much value as possible (DuHadway et al., 2019).

Risks are also categorized depending on where they are located in the supply chain relative to the company: *supply-side*, *operations and manufacturing*, and *demand-side* risks (Chatterjee & Kar, 2016; Shenoi et al., 2018; Sreedevi & Saranga, 2017). A distinction is also made between *operational risks* occurring frequently as part of normal variation in production, and *disruption risks* which are less common and more coincidental (El Baz & Ruel, n.d.; Song et al., 2024). According to Fischer-Preßler et al. (2020), operational risks are caused internally, whereas disruption risks originate in the external environment. They further argued that specific organizations in the supply chain are able to prevent operational risks, but that disruption risks must be addressed with SCRM through measures like contingency planning or resilience

capabilities (Fischer-Preßler et al., 2020). Furthermore, risks can appear on different aggregation levels: *macro level*, *supply chain level*, or *company level risks* (Diabat et al., 2012; DuHadway et al., 2019). Risk taxonomies aiming at mapping causality between different supply chain risks differ from established classification schemes. These attempts capture interdependencies (Qazi et al., 2018). *Network risks* come from different supplier layers, vendor strategies, and agreements in the supply chain (Gurtu & Johny, 2021).

Ways of Categorizing Risks	**Papers**
Impact and probability	Fischer-Preßler et al. (2020), Urciuoli & Hintsa (2018)
Endogenous, exogenous, intentional and unintentional/inadvertent risks	(DuHadway et al., 2019; Rauniyar et al., 2023) Urciuoli & Hintsa (2018) (Gurtu & Johny, 2021)
Supply-side, operations and manufacturing, demand-side risks	(Chatterjee & Kar, 2016; Shenoi et al., 2018; Sreedevi & Saranga, 2017), (Gurtu & Johny, 2021)
operational and disruption risks	(El Baz & Ruel, n.d.; Song et al., 2024) (Fischer-Preßler et al., 2020)
Macro level, supply chain level, company level	(Diabat et al., 2012; DuHadway et al., 2019)
Network risks	(Gurtu & Johny, 2021)
Sources of risk and mitigation strategies	(Gurtu & Johny, 2021)

Table 1 Different Taxonomies of Risk

Within each of these taxonomies there exist different types of risk, and the types of risks may be numerous. Fischer-Preßler et al. (2020) found that risks stem from a focus on efficiency rather than effectiveness in supply chains, increasing demand and supply uncertainties, new sourcing structures, globalized markets, and shorter product life cycles. "*A supply chain is as strong as the most vulnerable member of the supply chain*", and the probability of risks materializing grows as a function of supply chain length (Gurtu & Johny, 2021). Each supply faces unique risks, but some risks are common across supply chains (Gurtu & Johny, 2021).

There is no consistency in what risk factors are proposed in different papers, but some broader aggregated themes can be derived. *Environmental risks* are beyond the control of the company and are often natural events or disasters causing physical damage or resource shortages. These include environmental risks (Oliveira et al., 2019), natural calamities, and infrastructure risk (Dohale et al., 2022). Close to all papers deal with *demand and supply risks* (Alora & Barua, 2022; Dohale et al., 2022; Oliveira et al., 2019; Shenoi et al., 2018). Demand risks include market changes and demand uncertainty, whereas supply risks concern the availability and

reliability of suppliers (e.g. transportation failure), logistic risk, and stock levels (Dohale et al., 2022; Gurtu & Johny, 2021; Shenoi et al., 2018). These risks must be monitored closely.

Financial risk are caused by changes in prices, currency exchange rates, or unforeseen financial challenges regarding cash flow, credit, and the financial stability of supply chain partners (Alora & Barua, 2022; Dohale et al., 2022, 2023; Oliveira et al., 2019; Shenoi et al., 2018). These risks may propagate through the supply chain, harming operations and supply chain relationships. *Process and operational risks* affect daily operations. Examples of this group are employee unavailability or turnover, lack of coordination and alignment (Dohale et al., 2022), control and process inefficiencies (Alora & Barua, 2022; Oliveira et al., 2019), and information sharing failure (Dohale et al., 2022). These risks affect the extent to which companies achieve their goals, especially when critical processes or people are affected. Robust planning and mitigation strategies are necessary to manage these risks.

Institutional and regulatory risks, like changes in laws, regulations, and institutional policies, affect the business environment and supply chain operations (Dohale et al., 2023; Shenoi et al., 2018). At the same time, non-compliance might lead to disruptions, delays, and legal complications. The company must therefore stay updated on these changes at all times. A last group is *uncertainty risks*. These are unpredictable factors or unforeseen disruptions, so called black swans. They mostly emerge from external factors like economic shifts, geopolitical changes, or the pandemic (Dohale et al., 2022, 2023). These often overlap with other risks and flexibility and adaptability in risk management is needed to manage them.

During COVID-19, the general research focus was on solving pandemic-related risks, which were unpredictable but highly critical. The disruption caused by the global pandemic must however be considered as a deviation from the normal and as having low probability. Given the limited resources in a company, proactive mitigation strategies of pandemic-type risks cannot be expected. Instead, they may be managed with reactive strategies enabled through identification of disruptions at an early stage, SC robustness, SC resilience, and SC flexibility (Dohale et al., 2022). Such risks must also be acknowledged and closely monitored.

2.1.3 The Supply Chain Risk Management Process

Risks cannot be eliminated, but mitigated (Babu et al., 2021). Risk management is the activity and process of implementing strategies and plans to manage supply chains through constant risk assessments, and to minimize vulnerabilities of the supply chain (Gurtu & Johny, 2021). Despite some different opinions regarding the number of steps this process consists of, it contains (1) identification, (2) analysis and assessment, (3) mitigation, and (4) risk control and monitoring (DuHadway et al., 2019; El Baz & Ruel, n.d.; Kamakela et al., 2023; Lachapelle & Hundozi, 2015; Qazi et al., 2018). Risk mitigation is the most commonly researched of the four SCRM areas (Fischer-Preßler et al., 2020). Risk identification lays the foundation for the following risk management processes and it therefore plays a central role in determining the outcomes of the process (El Baz & Ruel, n.d.). Aboutorab et al. (2021) also highlighted the centrality of reviewing company objectives. They saw it as the starting point of the risk management process, even preceding risk identification, because risk management should be conducted in accordance with the general company objectives, policies, and risk criteria. Qazi et al. (2018) stressed that SCRM is a coordinated effort among supply chain members.

There are both *proactive* and *reactive* risk management approaches SCRM (Dohale et al., 2022; DuHadway et al., 2019). Proactive approaches seek to avoid or mitigate risks before they materialize, whereas reactive approaches focus on minimizing the impact and duration of a disruption after the risk has materialized (Ivanov et al., 2019). Companies tend to be more reactive than proactive (Fortner, 2021), and risk management strategies score below the risk level, meaning risks are not sufficiently addressed in companies (Shenoi et al., 2018). SCRM approaches can also be categorized as (1) focused approaches targeting specific issues such as security, lead times, or terrorism, or (2) comprehensive risk management approaches treating risks holistically (Gurtu & Johny, 2021). Similarly, Lachapelle & Hundozi (2015) distinguished between (1) applications to specific processes, projects, activities, or company divisions, and (2) holistic approaches applied across the company or supply chain.

Several qualitative and quantitative frameworks have been used to identify, assess and manage risks (Qazi et al., 2018). What can be considered optimal risk management for a company depends on its internal and external contexts. Manufacturers and suppliers have different needs and perceptions of supply chain risks. Shenoi et al. (2018) found a service-gap in risk management, highlighting discrepancies between the perceived importance of risks and how effectively they are managed. Similarly, Kamakela et al. (2023) observed a mismatch between the actual risk level and SCRM efforts undertaken in companies. Each company has its own

reasons for conducting SCRM, influenced by internal activities and processes, but also their history with supply chain partners (Grötsch et al., 2013). In other words, there is a high demand for better SCRM closer aligned with company strategies and actual risk levels.

The existing frameworks have been faced criticism for several reasons: (1) they fail to address common cause failures and their propagation impact, (2) their fragmented focus is limited to only a few stages rather than the entire SCRM process, and (3) they do not consider the role of risk appetite in processes (Qazi et al., 2018). Risk appetite refers to the risk willingness and aversion of supply chain managers. For example, how much a risk manager spends on risk management strategies depends on how important the decision-maker considers the cost of impact (Qazi et al., 2018). The trade-off between risk management and cost is therefore exposed to subjective judgement of the decision-maker, and the marginal reduction in risk level might not justify the marginal cost of additional investments. Building robust supply chains is expensive, but given budget constraints, it is argued there could exist an optimal cost-risk ratio for a company (Gurtu & Johny, 2021). Analysing a portfolio of combinations could also be necessary to find the optimal trade-off (Qazi et al., 2018).

Risk Identification

Risk identification is the process of identifying what risks the company is facing and is the first phase of the risk management process (Fischer-Preßler et al., 2020). It includes identifying the risks and what impact they may have on objectives like milestones, finances, and project scopes (Belgodere et al., 2021). To manage and mitigate risks, the risks must first be identified. It is hard to identify and assess sources of risks within supply chains because companies must consider not only risks directed towards themselves, but also those affecting supply chain partners (Fischer-Preßler et al., 2020).

The risks should be identified as precisely and specific as possible, with a clearly defined and self-explanatory title (Belgodere et al., 2021). The task of risk managers is to stay in touch with responsible people and to develop response plans. There are several qualitative and quantitative approaches to risk identification (Aboutorab et al., 2021). These methods range from analysis of existing documentation, interviews, brainstorming, failure modes, cause trees, previous encounters, pre-established check lists, and questionnaires (Belgodere et al., 2021).

A central issue highlighted by Ganesh & Kalpana (2022) is the use of historic data in risk management rather than real-time data from sources such as social media and newspapers.

Although helpful in identifying risk factors, historic data provides no grounds for monitoring the development of risks. Due to increasing turbulence across markets, there is a growing need for early risk identification, making real-time and proactive approaches necessary (Ganesh & Kalpana, 2022). An emerging branch of research concerns risk identification through social media (Fischer-Preßler et al., 2020). For example, Ganesh & Kalpana (2022) proposed an approach where data was extracted from social media and newspaper agencies to obtain real-time data, which thereafter was fed into analytical tools. They argued that data-driven approaches became a necessity with globalization and acquisition of vast amounts of data, and listed solutions ranging from AI assisted text mining and advanced data analytics, to data mining techniques and social media analysis. Early risk identification makes it possible to act and react at an early stage, thereby confining and reducing the risk impact and scope (Ganesh & Kalpana, 2022). With the rise of digital solutions, the role of the risk manager is expected to shift toward confirming techniques with minimal intervention (Aboutorab et al., 2021).

Aboutorab et al. (2021) looked at the effectiveness of different risk identification techniques in modern supply chains and argued that risk identification efforts in companies focused too much on internal factors, disregarding the environmental impact on company processes. Closed-loop risk identification typically focuses on internal feedback mechanisms within the company, limiting its scope. In contrast, open-loop risk identification expands the focus to include external data sources and environmental factors. Instead of a closed-loop risk identification, companies should adopt open-loop risk identification. Prerequisites for open-loop include aspects from several different areas like data science, information retrieval, knowledge management, decision-making, and operations management.

Aboutorab et al. (2021) also found that proactive techniques fared better than reactive techniques, both in detecting new risks and in providing an open-loop identification process. The trend in research papers shows the same result, as proactive risk identification techniques have spiked more than reactive and predictive techniques (Aboutorab et al., 2021). For example, techniques like HAZOP (hazard and operability) and FMEA (failure modes and effects analysis) explain how a system may fail, but not when or how to prevent failure. Only few techniques included open-loop information in risk identification, and for the most part, managers based their risk identification upon historic data. Status quo monitoring to predict risk events was underutilized, and SCR managers lacked sophisticated techniques and open-loops common within other domains (Aboutorab et al., 2021). In practice, reactive techniques are the norm.

Supply chain risks can be identified either passively, proactively, or reactively (Grötsch et al., 2013). *Passive identification* translates into chaotic reactions after a risk materializes. *Proactive identification* is not clearly defined but relates to actions taken in advance to prevent risks from materializing. Proactive risk management incurs costs even when the risk does not materialize. *Reactive strategies* are developed in advance but implemented after risk materialization with the goal of minimizing the impact rather than the possibility of occurrence. Proactive detection systems depend on what-if models and sensitivity analysis. Reactive detection systems alert management of risks in time to apply countermeasures and are made to draw the attention of decision-makers (Grötsch et al., 2013).

Risk Assessment

Under risk assessment we understand the assessment of the impact and probability of identified risks. Oliveira et al. (2019) categorized risk assessment into (1) quantification of impact and probability, (2) risk prioritization, and (3) selection for the mitigation phase. In qualitative risk assessment, the criticality of risks is analysed, then ranked and prioritized accordingly. The criticality of a risk is the product of probability and impact: criticality = probability * impact. Risks of higher criticality receive more attention. Probability is derived from experience of risk experts and is measured in percentage (Belgodere et al., 2021; Richert & Dudek, 2023). It is hard to determine the probability of risks, but risks that frequently materialized in the past are considered to have a high likelihood of materializing again (Grötsch et al., 2013). Impact is derived from assessing the total impact of the risk in the case it materializes and is measured according to a scale. Quantitative risk assessments analyse the financial impact of a risk and are carried out by the risk owner, but the process itself incurs costs. Quantitative assessments measure and compare the additional costs of risk management against the cost materialization (Belgodere et al., 2021). There are two different approaches to risk assessment. On the one hand are the traditional approaches with impact-probability risk matrixes. On the other hand is a new and emerging approach, focusing on risk interdependencies, risk entanglement and risk networks (Qazi et al., 2018). For the most cost-effective risk management approach, one should consider both the position in the risk network, risk mitigation effectiveness, attached cost and the risk tolerance of the decision-maker (Qazi et al., 2018). Risk assessments could also include multi-criteria decision making (MCDM) approaches where several variables are taken into account in decision-making (Ganesh & Kalpana, 2022, p. 1335).

Risk Mitigation

Risks are inevitable, but to achieve better performance, proper and timely implementation of countermeasures is necessary (Shenoi et al., 2018). There are several ways of managing risks, and optimal risk management depends on characteristics of the supply chain. Reducing the dependency on certain players, having backup plans in place if something goes wrong, and building trust and strong relations with supply chain partners have all proven beneficial for securing demand (Gurtu & Johny, 2021). Inventories of critical factors of production, also called safety stocks, reduce the impact of supply risks (Gurtu & Johny, 2021). There is a distinction between risk mitigation strategies and responses (Oliveira et al., 2019). Strategies are developed based on risk preference and/or attitude, and to what extent the risk manager and organization are risk averse, risk neutral, or risk seeking. Risk responses relate to generic responses and the type of countermeasure (Oliveira et al., 2019). However, in the literature, 'risk responses' are often referred to as 'strategies'. In this thesis, I will therefore use 'risk strategies' to refer to responses and the different types of countermeasures.

The generic risk mitigation strategies include mitigation or prevention, avoidance, acceptance, transfer and sharing, but also ignoration (Belgodere et al., 2021; Khan & Keramati, 2023; Oliveira et al., 2019). Belgodere et al. (2021) proposed a framework for allocating each strategy to different risks depending on their likelihood and impact. *Mitigation* as a strategy, the act of reducing the likelihood or impact, is the most suitable for high probability-low impact risks like complexity, risk of cost, and inbound threats. High probability-high impact risks should be managed with risk *avoidance*, removing the risk completely by choosing other alternatives. Such risks include web application failure and talent shortage. Risk *acceptance*, acknowledging the risk without implementing any countermeasures to combat the risks, works for low probability-low impact risks like loss of jobs and lack of management support. *Transfer and sharing* through for example insurance, or reliance on external service providers taking responsibility for the risk, are most suitable for disruption risks with high impact and low probability, e.g. cybercrime and data loss. Additionally, it is always an option to *ignore* the risk, but this approach is never recommended (Belgodere et al., 2021). Qazi et al. (2018) found that all risk mitigation strategies they studied were negatively correlated to all risks, which can be interpreted as no risk strategies increasing the impact or likelihood of any risks. The risk mitigation strategies scrutinized either had a positive effect or no effect.

Before managing risks, a risk treatment plan must be in place (Belgodere et al., 2021). The objective of the plan is to reduce the probability (preventive action) and/or impact (mitigation

action) of the risk. A treatment plan devises a clear action and purpose, a responsible person, and a deadline. When the probability of a risk reaches 100%, it ceases to be a risk and becomes an issue. All actions incurring costs must be tracked (Belgodere et al., 2021).

Risk mitigation strategies can be categorized as either proactive or reactive as outlined in table 2 below. Successful implementation of proactive risk mitigation depends on both internal and external factors, and one must therefore approach risk management holistically. Companies with low levels of SCRM used reactive mitigation strategies like flexibility and risk pooling after disruptions occurred (Sharma & Bhat, 2014). Reactive mitigation strategies have become the norm, but to improve the level of SCRM, companies should adopt proactive SRCM strategies like avoidance, supplier development, and integration (Sharma & Bhat, 2014).

Proactive Strategies	References	Reactive Strategies	References
Conjecture	(Gurtu & Johny, 2021)	Acceptance	(Belgodere et al., 2021)
Control	(Gurtu & Johny, 2021)	Collaboration	(Dohale et al., 2022; Sharma & Bhat, 2014)
Flexibility	(Dohale et al., 2022; Sharma & Bhat, 2014)	Mitigation	(Belgodere et al., 2021)
Integration	(Sharma & Bhat, 2014)	MSFC	(Dohale et al., 2022)
Numerical/economic approaches	(Gurtu & Johny, 2021)	Postponement	(Dohale et al., 2022)
Prevention	(Gurtu & Johny, 2021)	Redundancy	(Dohale et al., 2022; Sharma & Bhat, 2014)
Rescheduling	(Gurtu & Johny, 2021)	Risk pooling	(Sharma & Bhat, 2014)
Risk avoidance	(Shenoi et al., 2018; Sharma & Bhat, 2014)	Risk sharing	(Shenoi et al., 2018)
Risk monitoring	(Shenoi et al., 2018)	Visibility and transparency	(Dohale et al., 2022)
Risk plan	(Shenoi et al., 2018)	Ignore	(Belgodere et al., 2021)
Share and transfer	(Gurtu & Johny, 2021)		
Supplier development	(Sharma & Bhat, 2014)		
Vertical integration	(Gurtu & Johny, 2021)		

Table 2 Proactive and Reactive Risk Mitigation Strategies

Risk Monitoring and Control

The fourth phase of the risk management process involves keeping track of risk developments and managing them, namely risk monitoring. By tracking the development in markets through different data sources, the company can detect changes in the risk environment. Risks should be monitored daily as both risk probability and impact can change over time, sometimes rapidly (Khan & Keramati, 2023). An increase in either impact or probability translates into increasing risk levels. Ganesh & Kalpana (2022) proposed a method of using text mining and textual analysis of social media and news platforms for real-time updates of the market, where trends

in the use of certain keywords could indicate market changes. In the same way, regular updates of the risk assessment would point out changes in the data material and areas of concern to the company. According to Ganesh & Kalpana (2022), continuous monitoring leads to proactive behaviour. Risks must be constantly monitored and reported, but the frequency of monitoring should correspond to the assigned criticality of the risk factor (Belgodere et al., 2021).

2.1.4 Interconnected Risks

There is a tendency to study risks in isolation, although they are interconnected and should be considered holistically (Qazi et al., 2018; Urciuoli & Hintsa, 2018). There is little focus on holistic frameworks integrating all stages of risk management and the cascading effects of common risk triggers. The focus is often optimization of single objectives rather than the trade-offs between conflicting and interdependent objectives (Qazi et al., 2018). In most cases, risks are treated independently and tools for understanding and managing sophisticated interconnections are rarely applied in practice. The potential of advanced tools is often underappreciated until damaging risks materialise that simplistic risk matrices were unable to identify and assess (Qazi et al., 2018).

When risks are interconnected, the value and effect of risk management is greater than if there was no interconnection (Qazi et al., 2018). To achieve the highest effect per investment, one should target interconnected risks. However, some risks may be negatively correlated to other risks, meaning that the materialization of these reduce the materialization of other and potentially more harmful risks. In other words, less harmful risks may function as “buffers” against harmful risks. When deciding on risk management strategies one should therefore consider the effects on the network of risks rather than strategies aimed at individual risks. In the worst case, targeted risk strategies could solve these “buffer risks” and increase the overall risk level of the system (Qazi et al., 2018). Following this logic, the best allocation of resources would be to focus on non-critical risks instead of critical risks, given they interconnected with or could trigger other risks. For the most cost-effective risk management approach, one should consider both the position of risks in the network, risk mitigation effectiveness, attached cost and the risk tolerance of the decision-maker (Qazi et al., 2018). This clearly contradicts the traditional view on risk management at the bottom of impact-probability matrices and other frameworks. However, in the same article Qazi et al. (2018) also found that no risk mitigation strategies increased the probability or likelihood of any risk.

Nevertheless, tools based on network theory and Interpretive Structural Modelling (ISM) have an increased potential for assessing such intricate relationships. Risk networks are effective in information visualization and of significant assistance when looking at the relative probability and propagation impact of SC risks. These tools allow a holistic view on the positions of risks in the network, their influences and probabilities (Qazi et al., 2018).

2.2 Supply Chain Risk Management and Technology

2.2.1 Introducing Technology

The Oxford University Press (n.d.) defines *technology* as the practical application of scientific knowledge in industry, and Cambridge Dictionary (n.d.) defines *digital* as "*something relating to computer technology, especially the internet*". Digital technology must therefore encompass the practical application of scientific knowledge through computer technology and the internet in industry. The focus in this thesis will be on the ways technology can assist and improve SCRM, not on cyber risks and other risks linked to introducing technology into a company or supply chain. Organizational Information Processing Theory (OIPT) states that there is always uncertainty in the data of a company, and hence equivocality – the ways in which information can be interpreted (DuHadway et al., 2019). Uncertainty and equivocality make it hard to identify risks and predict disruptions. As information uncertainty and equivocality increase, the information processing requirements of the firm increase (DuHadway et al., 2019). Measurements, data, and forecasting techniques differ between countries, and these factors limit the accuracy that can be derived from forecasting models (Nikolopoulos et al., 2021). In other words, there is an increasing need for digital technology.

2.2.2 How Technology Can Assist and Improve SCRM.

Effects of Technology

There exists a consensus among researchers about the positive effects of technology on risk management and other company processes. The list of benefits is very long, but central elements are real-time information and alerts, higher data quality, data visibility, and information sharing (Akhavan & Philsoophian, 2023; Balakrishnan & Ramanathan, 2021; Doetzer & Pflaum, 2021; DuHadway et al., 2019; Fortner, 2021; Ivanov et al., 2019; Kamakela et al., 2023; Nayal et al., 2022; Song et al., 2024; Urciuoli & Hintsa, 2018). In proactive risk management, technology

improves demand responsiveness and capacity flexibility. In reactive risk management, advanced tracking and tracing technologies, together with big data analytics, enable new data coordination and SC visibility (Ivanov et al., 2019).

Fischer-Preßler et al. (2020) explain how technology can be used at each of the SCRM stages. Visual supply chain mapping could improve risk identification by visualizing the upstream and downstream flows of goods, information and money. Risk analysis, they argued, reaches deeper into the extent of losses incurred by the risk if it materializes. Data-analytical and modelling techniques could assist decision-making processes and lead to higher quality decisions. IT can improve risk reduction through data acquisition, traceability, and recording of flows. In risk monitoring, risk reduction activities are evaluated and risk auditing procedures instated. IT can provide structured catalogues of all information related to all identified risk factors (Fischer-Preßler et al., 2020).

In addition to positive effects, technology also reduces the potential impact and likelihood of negative effects (Fortner, 2021). For example, risk networks are effective in information visualization and of significant assistance when looking at relative probability and propagation impact of supply chain risks (Qazi et al., 2018). The risk network allows a holistic view on the position of risks in the network, their influences, and probabilities. Likewise, proactive detection systems are enabled through what-if models and sensitivity analysis. Meanwhile, reactive detection systems alert management of risks in time to apply countermeasures and are made to catch the attention of decision-makers (Grötsch et al., 2013).

Digital Systems

A distinction is made between mechanistic and organic SCRM systems. Mechanistic systems are formal and installed structures, whereas organic systems are informal and flexible (Grötsch et al., 2013). Due to the rule-based and structured problem solving of mechanistic systems, they are better suited for proactive risk management. Technology and digital systems follow set rules and can be considered mechanistic systems. Mechanical control systems led to more proactive behaviour and risk management due to a logical layout, formalized decision-making routines and procedures, as well as frequent and thorough operation. Clear and defined rules give a more systematic approach to risk management (Grötsch et al., 2013). Zimon & Madzik (2020) labelled mechanical control systems as standardized management systems and found that those systems led to formalized procedures in the company (Zimon & Madzik, 2020). Formalized

procedures in turn had significant positive impacts on "*customer satisfaction, proper implementation of logistics processes, effectiveness and timeliness of actions, error prevention and repeatability*" (Zimon & Madzik, 2020, p. 320).

In their study, Sambhara et al. (2016) found that investing in IT resources improved organizational productivity, organizational efficiency, market valuation, and financial performance. They also delved further into different digital systems and identified three different kinds. The first, *Enterprise Systems* (ES), are large, complex, all-encompassing but expensive systems. Enterprise systems reduce information risk, but also reduce transaction costs and coordination issues, improve information processing, and reduce supply, demand and quality uncertainties. ES helped companies address and mitigate operational risks in complex and uncertain environments (Sambhara et al., 2016). The second kind are the more specialized *Complementary Enterprise Systems* (CES) and include HR, CRM, and Supply Chain systems. CES enable a value-chain framework and ES within CES performs tasks assisting the assigned process to improve mobilization, tabulation and transmission to succeed with the process (Sambhara et al., 2016). In complex environments there is a higher need to digitize cross-functional processes and hence a larger need for complementary enterprise systems (CES) (Sambhara et al., 2016). The third kind were *Accounting Enterprise Systems* (AES) used for managing and streamlining financial accounting processes.

Firms prefer CES (Complementary Enterprise Systems) over AES (Accounting Enterprise Systems) when the information risk increases, although companies with weak internal controls implementing AES rather than CES. The implementation of CES was nevertheless higher than for AES. In complex and dynamic environments, CES are implemented to a greater extent than was AES. Implementation of ES depended on both the internal and external business environments (Sambhara et al., 2016). In dynamic environments, the company must adapt and respond to changing consumer demands, making a variety of information on customer buying behaviour is important and necessary. Additionally, real-time supplier information is essential for minimizing lead times. CES is therefore implemented to a larger extent in dynamic environments where information sharing with suppliers is vital (Sambhara et al., 2016).

Enterprise risk management (ERM) has been popularized both in academia and the corporate world due to international standards and is applicable to all kinds of businesses (Villanueva et al., 2022). ERM is a process and system consisting of risk detection, analysis, and development of countermeasures to manage the risks. To work optimally, risk detection and control systems must be closely integrated with company strategies and risk mitigation. These are two sides of

the same coin and must be treated as such (Grötsch et al., 2013). ERM systems have reduced the cost of capital and created value for companies, but the system development depends on the company context and its structure is sometimes too rigid to adaption or to model risk complexities (Villanueva et al., 2022). Determining factors for ERM development are "*senior management commitment, risk management structure, defined guidelines, a risk-conscious culture, risk appetite and tolerance, as well as risk identification, analysis, and response, among other elements*" (Villanueva et al., 2022, p. 190). Size and age of the company did not incluence ERM development (Villanueva et al., 2022).

2.2.3 Improved Data Collection, Quality and Analysis

In dynamic environments, companies must adapt and respond to changing consumer demands, and access to a variety of information on customer behaviour is important and necessary. CES is therefore implemented to a larger extent in dynamic environments, but also information sharing with suppliers is of significance (Sambhara et al., 2016). New technologies such as smartphones, Internet of Things (IoT), and enterprise resource applications, improve data collection (Kamakela et al., 2023). With more data it is possible to triangulate issues, and easier detect discrepancies and issues in the data material, which in turn lead to higher data quality. Improved data quality and information sharing enables risk mitigation, resilience, and responsiveness (Nayal et al., 2022). Nikolopoulos et al. (2021) also showed how additional information can be incorporated into simulations and scenario analysis to predict potential disruptions and situations where risks materialize.

One of the benefits of emerging technology is real-time data collection. Technology can provide real-time information on the scope and scale of disruptions, propagation in the supply chain, and simulations on how to counter them (Ivanov et al., 2019). Furthermore, technologies can improve SCRM through real-time information sharing among supply chain partners, system alerts, end-to-end supply chain mapping, traceability for better compliance, improved continuous risk monitoring, and better impact assessments (Ivanov et al., 2019; Nayal et al., 2022). Integration with suppliers can enhance risk identification through information sharing on performance metrics, demand forecasts, production and delivery schedules, and inventory and sales data (Nayal et al., 2022). Information sharing, supply chain visibility, and supplier integration are also effective in risk detection (DuHadway et al., 2019). High-quality data management standards lead to more efficient management of irregularities, fewer errors, and

improved information flow in the supply chain. Improved information flow leads to better risk assessment and decision-making in the supply chain. (Zimon & Madzik, 2020).

Risk maps visualizing data are positively related to ERM development, meaning constantly updated risk maps, at different organizational levels, improve and mature the risk response system. Constant updates are however necessary to maintain the value of risk maps (Villanueva et al., 2022). Furthermore, different technologies and their effects influence one another. For example, real-time data enhances visibility (Kamakela et al., 2023).

Despite the technological improvements in high-quality data collection, some issues remain. For example, data formats, data regulations, measurements, and forecasting techniques differ between countries and can limit the accuracy achievable from forecasting models (Nikolopoulos et al., 2021). Additionally, with increasing amounts of data, more data capacity is needed to manage the velocity, volume, and variety of the Big Data. In fact, too much information could lead to information overload and decision paralysis (Getele & Ruoliu, 2022). As mentioned before, all data contains uncertainty and equivocality according to organizational processing theory (OIT). Uncertainty and equivocality can also arise from large amounts of data (DuHadway et al., 2019; El Baz & Ruel, n.d.). When uncertainty increases, so too does the magnitude of disruptions (DuHadway et al., 2019). Simply put, improved data collection is ineffective without sufficient analytical tools for managing and making sense of the data.

To deal with the large amounts of data, uncertainty, and equivocality companies need to develop their dynamic capabilities and their information processing capabilities (DuHadway et al., 2019; El Baz & Ruel, n.d.). Dynamic capabilities are the ability of a company to integrate, build and reconfigure resources to adapt to changes in the environment (El Baz & Ruel, n.d.; Song et al., 2024). By increasing the dynamic capabilities of the company and supply chain, they are better equipped to deal with uncertainty and data risks, improve risk identification, and increase the quality and effectiveness of other risk management processes. Companies with dynamic capabilities, such as continuous learning, are better at identifying risks, activate and reallocate resources, and restructure the supply chain to quickly adapt and respond to changes (Song et al., 2024). The ability to adapt to rapid changes also provides them with a competitive advantages, such as the first-mover advantage (DuHadway et al., 2019; Song et al., 2024).

IoT, combined with AI, can provide learning capabilities and structured interpretations of unstructured data, but also assist with predicting dynamic patterns in the market and environment (Nayal et al., 2022). Tools can make information more accessible and readable,

thereby removing some of the information risk. Data visibility and insights can help SC risk managers interpret and understand information (Fortner, 2021). Combined with real-time data on global events, improved data collection, and quality, technologies like machine learning (ML), deep learning (DL), and big data analytics (BDA) can deliver more powerful and accurate forecasts (Balakrishnan & Ramanathan, 2021; Nikolopoulos et al., 2021). AI can also be used within advanced predictive analytics and expert systems, as well as demand forecasting (Nayal et al., 2022). Put differently, digital technology can assist in decision-making.

Analytical tools can also assist in supplier screening and selection (Fortner, 2021) by reducing the risk of choosing bad suppliers and hence the potential for supply risks with that supplier. Automated supplier quality management can detect external issues before they escalate (Fortner, 2021). Higer data quality improves data visibility and real-time insights on supply chain ordering, movement of materials, and supplier information, while blockchain makes it easier to track products precisely (Balakrishnan & Ramanathan, 2021). End-to-end supply chain visibility furthermore enhances supply chain planning and strategic sourcing decisions.

Digital technology can moreover assist with digital contracts, freight booking, dynamic asset management and planning, contactless delivery processes, building RPA as part of the digital workforce, and with automated product handling and warehouse management (Balakrishnan & Ramanathan, 2021). For some activities, Doetzer & Pflaum (2021) argued that risk managers can be fully replaced. If or when digital tools and systems replace risk managers, decision-support systems should be based on the three principles of (1) "*integrated modelling of resilient network structures*", (2) "*proactive planning and network redundancy optimization"*, and (3) "*situational proactive control*" (Ivanov et al., 2019).

Considering the SCRM activities, Rauniyar et al. (2023) found positive effects of digital technologies on risk analysis, enabled by higher efficiency, lower costs, and organizational growth. Tools based on network theory and ISM have high potential for assessing driving factors and consequences of risks, providing deeper insights. Risk networks are effective in information visualization and of significant assistance when looking at the relative probability and propagation impact of SC risks. The risk network allows a holistic view on the position of risks in the network, its influence and probability (Qazi et al., 2018). In other words, improved collection processes and higher data quality, combined with analytical and decision management tools, will improve SCRM by assisting and informing risk managers. Through technology risk managers obtain an easier access to important information in their work.

2.2.4 Digitalization, the Bottom Line, and Strategic Advantages

Replacing workers has led to cost reductions for complex tasks, but it has also reduced learning costs and costs for expert-level decisions (Nayal et al., 2022). Technology can mitigate hitches on delivery and breakdowns of machines and equipment, improve quality, and assure product availability (Nayal et al., 2022). More sensors and improved data collection can provide warnings before machines break down and digital technologies can reduce operators' workload through more efficient production planning (Nayal et al., 2022). Technology, therefore, can provide competitive and strategic advantages by improving the competitiveness of both individual companies and their supply chains (Tipu & Fantazy, 2023). Better product quality, availability, and customization allow higher prices and a better price-to-quality ratio. Combined with higher efficiency, productivity, and therefore cost reductions, technology improves both the top and bottom lines (Nayal et al., 2022; Tipu & Fantazy, 2023). Nayal et al. (2022) argues that industry 4.0 technologies improve productivity and work conditions, which in turn lead to higher worker retention and attraction. In turn, attracting more qualified talent could mean smarter solutions and higher quality decision-making. Digitalizing operational tasks moreover frees up human resources for more tactical, strategic, and long-term tasks (Kessler et al., 2024).

Standardized management systems have proven beneficial for SCRM independent of the company's position in the supply chain, but they vary in significance (Zimon & Madzik, 2020). Zimon & Madzik (2020) argued that companies with limited budgets should implement standardized management systems. ERM is applicable to all kinds of businesses (Villanueva et al., 2022), much in the same way as are standards (Qazi et al., 2018). ERM systems have reduced the cost of capital and created value for companies (Villanueva et al., 2022).

Costs are the main factor deterring companies from undergoing digital transformation (Kamakela et al., 2023). Additionally, it is hard to see any immediate benefits of improved supply chain flexibility (Sreedevi & Saranga, 2017). Kessler et al. (2024) found technology implementation to be more problematic in small and medium sized enterprises (SMEs). However, the risk manager is more important than the size of the company and there is no guarantee that larger firms have better SCRM than smaller firms (Sharma & Bhat, 2014).

Furthermore, focal companies manage to implement systems to support and improve the supply chain strategy, whereas this proves hard for logistics companies due to limited resources and information (Zimon & Madzik, 2020). Adaption of existing systems to fit supply chain requirements is hard for logistics operators, but cooperation with logistics providers in shaping

the supply chain could lead to increased effectiveness and reliability of the supply chain. Integrating logistics providers also strengthens the supply chain, allowing more sophisticated solutions for logistics and transport, technologies, organizational competences, and better customer service. Focal companies consider implementing management systems to have a higher impact than logistics operators do (Zimon & Madzik, 2020).

2.2.5 Big Data Analytics and AI

Better risk identification and analysis is one thing, but technology can also contribute to quicker recovery after disruptive events materialize (Balakrishnan & Ramanathan, 2021), plus provide more flexibility, agility, and resilience (Doetzer & Pflaum, 2021). Technology was for example found to have positive effects on supply chain performance through reduced disruption risk (Song et al., 2024). Big data analytics (BDA) can improve risk control, increase SC resilience, and minimize the propagation of the ripple effect (Gupta et al., 2022). BDA furthermore reduces information disruption risk, shorten the time of implementation, improve the quality of contingency plan implementation (Ivanov et al., 2019), and contributes positively to risk intelligence during disruptions (Gupta et al., 2022). However, BDA was more effective in identifying and managing risks than in preparing for disruptions (Gupta et al., 2022).

Meanwhile, AI increases supply chain resilience, flexibility, and robustness through real-time data collection, expert systems, error reduction and ML techniques (Nayal et al., 2022). Nayal et al. (2022) discovered an indirect relationship between information sharing and SCRM with AI as the mediator: information sharing positively affected AI, and AI positively affected SCRM. On the one hand, improved information sharing through digital solutions, in addition to implementing AI in SCRM tools, should therefore enhance the performance of SCRM activities. On the other hand, one may also draw the conclusion that information sharing is a prerequisite for obtaining the full benefit from AI.

2.2.6 Information Sharing

Information risk is related to the flow and use of data, information, and knowledge in and between different supply chain members (Dohale et al., 2022), where criticality of information risk depends on the company's ability to gather financial and performance information in different areas (Sambhara et al., 2016). Common data standards were proposed as solutions to

solve information risks (Fischer-Preßler et al., 2020). High-quality information sharing across the supply chain about performance metrics, demand forecasts, production and delivery schedules, and inventory and sales data, enable risk mitigation, resilience, and responsiveness (Nayal et al., 2022). Generally, companies want more information sharing to better track deliveries, using for example time stamps, to reduce the supply risk (Urciuoli & Hintsa, 2018). Digital platforms facilitate improved information flow.

A meta study showed that information sharing and collaboration was the main benefit of IT in SCRM (Fischer-Preßler et al., 2020). Information systems (IS) assists in several ways, including accurate capture and processing of financial data, coordinating information across the company, business units, functional domains and activities, and reporting to firm level (Sambhara et al., 2016). Transparency and information sharing are imperative to deal with changing business conditions and dynamic markets (Gurtu & Johny, 2021). A lack of visibility, technical communication, and insufficient network reliability and connectivity have been identified as major contributors for operational risks in industrial contexts (Fischer-Preßler et al., 2020). In contrast, collaborative capabilities and information sharing facilitate faster responses to occurring events, thereby contributing positively to SCRM (Gani et al., 2023). Information earlier in the supply chain give companies more time to react, cope with and prevent risks from materializing (Urciuoli & Hintsa, 2018). Supply chain risk management should therefore be conducted as a collaborative effort between all supply chain parties to achieve the optimal effect of each single firm's efforts, and digitalized information-sharing (DIS) is central for flexibility utilization in supply chain risk management (Doetzer & Pflaum, 2021).

There is a need to keep information in a central system with easy access for all authorized parties (Fortner, 2021), and to create a single source of truth for the supply chain (Balakrishnan & Ramanathan, 2021). Information sharing technologies can break down silos for better communication and centralized efforts, remove duplicated efforts, and improve time efficiency. The availability of strategic and tactical information in the supply chain enhances supply chain performance and strengthens SCRM (Fischer-Preßler et al., 2020). It enhances demand and production planning and reduces the probability of propagating risks, such as the bullwhip or ripple effects (Fischer-Preßler et al., 2020).

Although some companies have clear visions for developing information sharing, others do not (Urciuoli & Hintsa, 2018). Several reasons lie behind the disparity, two of them being the nature of the products and time criticality in industries such as ultra-fast fashion (Balakrishnan & Ramanathan, 2021). Urciuoli & Hintsa (2018) found that ocean carriers and third-party logistics

companies were reluctant to share information on labelling, transportation, location, and more with their supply chains despite the significant benefits of information sharing. Supply chain partners may not see or understand the benefits of information sharing (Saldanha et al., 2015).

2.2.7 Implications, Prerequisites, Assumptions, and Problems

Although there exists a consensus about the benefits of technology, there are several obstacles to overcome before achieving these benefits. Kamakela et al. (2023) found that companies perceive technology to have potential, but do not sufficiently implement it. The focus lies on mitigating risks rather than adopting and implementing comprehensive risk management strategies (Kamakela et al., 2023). Different kinds of technology come with different levels of technology and process uncertainty, and central questions are always what the technology can do and how it can be utilized optimally (Kessler et al., 2024). *Technology uncertainty* refers to a lack of lack of knowledge or clarity about the use, functionality, or potential outcomes of the technology. *Task uncertainty*, on the other hand, refers to the unpredictability or complexity in performing tasks due to the implementation of technologies. Without sufficient knowledge, experience, or insights, suboptimal technology utilization is inevitable. To succeed with digitalization, digital specialists, increased digital skills, and employee awareness is needed (Song et al., 2024). However, implementation of technology into work processes might create job uncertainty and fear among the employees about losing their jobs (Saldanha et al., 2015).

Neither should the inherit weaknesses and limitations of the technology be overlooked. For example, connected platforms are effective for real-time information exchange, but during disruptive events, the capabilities of traditional platforms are limited (Doetzer & Pflaum, 2021). In other words, the effectiveness of the technology depends on the situation and environment. Different solutions work in different scenarios, and achieving full protection may require combining different technologies. IT comes with its own risks, including cyber and security threats, exploitation of partner's information, technology breakdowns, and consequences of improper integration (Fischer-Preßler et al., 2020). Kessler et al. (2024) found that collaboration between humans and technology could, in fact, negative impact on managerial risk responses, regardless of whether the collaboration was perceived positively or negatively. In other words, technology does not necessarily make risk management easier because new complexities and uncertainties are introduced. Another remark made by Doetzer & Pflaum (2021) was that companies could achieve the same flexibility capabilities and information sharing benefits

through conventional and existing infrastructure. This may explain why some companies do not see or observe any immediate effects or additional benefits of technology, but instead only the large investment costs (Doetzer & Pflaum, 2021).

2.3 Conclusion Theory

Risk levels are increasing, and the longer and more complex the supply chain, the greater the uncertainty and the higher the likelihood of disruptions. There is a growing need for efficient and effective SCRM. The megatrend of digitalization contributes to this by improving data collection and quality, enhancing data analysis and management, facilitate information sharing between different supply chain parties, and providing real-time updates for continuous and improved monitoring and risk identification. However, there is a gap in the literature regarding the role of digital technology within SCRM. In addition there only being some literature in this area, the existing research is fragmented and focused on certain aspects of the risk management process rather than developing a holistic understanding. Companies also focus on technology for risk mitigation rather than improving their SCRM. The aim of this thesis is therefore to provide a holistic framework for understanding the role of digital technologies within SCRM.

3. Methodology

In this chapter the methodology of the thesis will be explained in depth and all choices justified with theory when applicable. The general structure starts from the overarching purpose and research approach, then funnels down to the more practical implications as the chapter progresses. At the same time, the chronology of this chapter reflects the chronology of the chapters of the thesis, but also the chronological order of steps in this project. The quality of the research design, use of ChatGPT, and ethical considerations are discussed at the end.

3.1 Research Purpose and Approach

The choice fell on a qualitative research approach because the use of digital tools and systems within SCRM is underdeveloped in the literature. The study is mainly exploratory, but with some descriptive and explanatory elements (Saunders et al., 2016, p. 174-176; Yin, 2018, p. 10). The aim with this approach is to explore and explain the driving mechanisms and relationships between elements and to build a theoretical framework to better understand the impact of digital technologies on SCRM. The study is also inductive, deriving patterns from the collected data to develop a framework (Saunders et al., 2016, p. 570-571).

3.2 Literature Review

At the beginning, a research proposal with clear objectives was developed to have a clear scope for the literature review. The process of writing the literature review consisted in several steps. First, the initial literature review on relevant topics generated a list of search terms (Appendix 1), provided an overview of the field, and developed my understanding of what results to expect (Saunders et al., 2016, p. 72). Second, a thorough literature review was conducted based on the search words to target specific areas within the research field. Third, the first draft of the literature chapter was made. From there on, the literature chapter became an iterative process alternating between thorough literature searches and drafts of the chapter.

3.3 Research Strategy and Approach – Multiple Case Study

A multiple case study was chosen as the research strategy for this thesis. It is an accepted and well-established research approach within several disciplines (Yin, 2018, p. 5), and it is used to understand complex social phenomenon with an in-depth focus on several cases while maintaining the holistic and real-world perspective. Yin (2018, p. 9-13) outlined a framework with criteria to help choose the most suitable research approach. Following this framework, the case study is the recommended research approach because (1) the questions asked is a "how" and "why" question, (2) the behaviour of the companies will not change and neither can the environment be changed (e.g. observer bias), and (3) the focus is on contemporary events. This approach provides an in-depth understanding of the phenomenon in its natural context. The boundary between the phenomenon of digitalization and the context of a changing business environment, is blurred, another argument for choosing the case study (Yin, 2018, p. 15). Case studies are realistic, which means they assume a given and single truth to be discovered and also assume that the answers to the research question will be the same independent of the context (Yin, 2018, p. 16). Data collection from several different companies provided a triangulation effect for uncovering this underlying realistic truth.

3.4 Data Collection Method – Semi-Structured Interviews

For the data collection, semi-structured interviews were chosen. Semi-structured in-depth interviews are qualitative and obtain qualitative information (Saunders et al., 2016, p. 391). As preparation for the semi-structured interviews, the interview guide was developed (Appendix 2) consisting of themes and key questions, but with the flexibility to omit or add questions depending on the development of the conversation, emerging topics, and the organizational context (Saunders et al., 2016, p. 391). Semi-structured interviews are used to answer "what", "how" and "why" questions through a qualitative approach (Saunders et al., 2016, p. 392-393). These interviews also provide context and understanding for exploratory studies and the relationship between variables in explanatory studies.

The interviews all followed the same structure outlined in the interview guide. First, the participants were informed about their rights to ensure informed consent, how the data would be treated and anonymized, and practical information about the interview. I also introduced myself as a researcher. Second, there was an opening question allowing the participant to

explain his/her position in the company and the company's position in the supply chain. Third, the interview progressed onto open-ended questions on the three topics of (1) SCRM in the company, (2) what technology they currently used, and (3) views on and experiences with the tools. During the interviews, clarifying questions were asked to make the participant elaborate and add more detailed on the topics. The flexibility of the semi-structured interviews allowed me as a researcher to probe the respondents through such follow-up questions. At the end, the participant could add information they felt were missing or ask their own questions.

3.4.1 Selecting the Sample

A non-probability sampling technique was used because there existed no sampling frame, and because the probability of selection from the target population was uncertain (Saunders et al., 2016, pp. 276, 295). The sampling technique was a mix between heterogenous, or maximum variation sampling, and critical case sampling. The reasons for this was to obtain a sample of important companies with sufficient variation to pinpoint the effects of technology on SCRM, to reduce and mitigate biases, and to obtain a representative sample (Saunders et al., 2016, p. 301). There are no clear rules on sample size, but recommendations for case studies and semi-structured interviews range from four to 25 (Barrat et al., 2011; Saunders et al., 2016, p. 297). In this study, the number fell towards the lower end with a total of six. Nevertheless, the aim of qualitative data collection is reaching data-saturation (Saunders et al., 2016, p. 297). Due to the large heterogeneity in companies, industries, and supply chain structures, this objective was unfortunately not satisfied. New information was provided until the very last interview. Further interviews should have been conducted to reach the goal of data saturation, but due to time constraints and a lack of respondents the data collection was terminated prematurely.

The companies were contacted via email (Appendix 3), and the open-ended interview questions from the interview guide (Appendix 2) were sent to the companies. This so they could decide and pick the people they considered the most capable of providing good answers to the questions. Although heterogenous, the companies shared some important characteristics:

- They were Norwegian companies.
- The companies were production and/or retail companies.
- They managed physical goods.
- The majority engaged in exports and/or imports.

The researcher being Norwegian, Norwegian companies enabled easier data access without cultural and language barriers interfering with interpretations and communication. Production and retail companies were chosen because supply chain activities and SCRM are central to their operation and financial performance. The majority also had some export or import activities exposing the companies to global supply chains and international markets.

Company	Industry	Operating Revenue 2023	Position in SC	Flow of Goods
Optimera	Building Materials and Construction Supply	NOK 11,264,688	Retail/Procurement	Import
Q-Meieriene	Dairy/Food	NOK 2,297,562	Production	-
Bergene Holm	Wood Processing and Timber	NOK 1,891,216	Production	-
Essity	Hygiene and Health Products	NOK 1,863,888	Retail/Procurement	Import
Sykehusinnkjøp HF	Healthcare Procurement	NOK 417,795	Retail/Procurement	Import
Vestre	Furniture Manufacturing	NOK 111,024	Production	Export

Table 3 Responding Companies

3.4.2 Data Collection

In total, seven participants were interview from the six companies. All the interviews were *internet-mediated* and conducted via Microsoft Teams. There was just one participant in each interview and with a single exception, only one person was interviewed per company. One of the respondents provided short answers to the questions by mail before the interview. These answers were added as an extension to the interview transcript from that participant. The first interview, although providing insights on the topic used in the analysis, functioned as a pilot study for the interview guide and the research approach. After the interview, the interview guide was updated and the research design improved on what appeared to be weak points. For example, the questions proved too specific and one-sided, not capturing all the important information and subtilties of the company. Due to a technical malfunction, the recorder stopped halfway through one of the interviews and a second interview was conducted one week later with the same participant. These two interviews were treated as one in the analysis.

3.4.3 Audio Recording and Transcription

The interviews were recorded using the Android application Voice Recorder and then uploaded to Microsoft Word for transcription using the Voice/Dictate function. The transcripts from Microsoft Word were not perfect and the data had to be cleaned to make sure the transcriptions correctly captured what the participants had said (Saunders et al., 2016, p. 572). This was done by listening through the recordings while reading the transcripts, correcting words and phrasing wherever there were errors. A total of 393 minutes of interviews – a little more than 6,5 hours – were recorded and transcribed.

The interviews were conducted in Norwegian to allow a better flow of information and to let the informants answer in the language they were most confident with. However, with different dialects, and one Swedish respondent, the transcription tool in Word provided only limited assistance and often made mistakes. The sound quality was sometimes poor because a phone microphone was used to record the interviews. Some parts were of such a low quality the passage had to be disregarded. The microphone sensitivity caused other problems. When I turned, checked the phone to make sure it was recording, or wrote on the computer, it created noise that made the recording hard to understand. These technical issues may have impacted the reliability of the results and conclusions in this thesis, but hopefully only to a limited extent.

3.5 Data Analysis Method – Thematic Analysis

The predominant data analysis method was thematic analysis (Saunders et al., 2016, p. 579-587). Thematic analysis looks for themes and patterns across data sets, is independent of the research philosophy, and can be used with both inductive and deductive methods (Saunders et al., 2016, p. 579). Because this is an inductive study, thematic analysis was used to look for patterns and themes in the interviews, and everything was coded to capture the nuances in the data. Topics for further analysis were also created ex post to the coding. With thematic analysis, prior interviews should be reworked when new codes emerge, in an iterative process of constant comparison (Saunders et al., 2016, p. 587). This was unfortunately not done due to time constraints. After familiarizing myself with the data by proofreading the interview transcripts and transcript summaries, I proceeded with coding and categorization of codes into themes. Both the coding and categorization were iterative processes (Saunders et al., 2016, p. 569).

The size of the unit of data varied from single words up to large paragraphs (Saunders et al., 2016, p. 580). New codes were created when the respondents delved into new topics or provided new perspectives on central themes. Whenever possible, codes from previous interviews were used to maintain consistency and to assist in the search for meanings, recurring themes, and the categorization of topics. To keep track of all the codes, they were systematised into a list with a clear label and definition. The codes were a mix of in vivo codes used by the participants (e.g. CRM), labels I developed to describe the data (e.g. system development), and some a priori codes based on theory (e.g. risk identification). In other words, a hybrid method was applied. The coding was conducted in Excel, where each unit of data was copy-pasted into different cells and with the code in the cell right next to it. 724 unique codes were identified, but luckily some of those were misspellings or had the same meaning but with different phrasing. The number of codes still had to be drastically reduced. Using Excel, the codes were systematized according to frequency. Less frequent codes were either merged into new codes or added to existing codes. For this activity I had to read all the places where the code had been used. This process resulted in 153 codes that then could be categorized into five themes (Appendix 4).

3.6 The Writing Process

Various summary techniques were applied at different stages of the process and later condensed into the respective sections of this thesis. During the literature review, interim and progress summaries were actively used to direct the search for keywords, topics, and relevant articles (Saunders et al., 2016, p. 576). When reviewing the articles, document summaries were created to keep track of important concepts, perspectives, and citations (Saunders et al., 2016, 577). These document summaries later served as the foundations for the literature chapter. After each interview, and during the transcription phase, transcript summaries were used to summarize and highlight the most important points of the interviews, emerging themes, connections with other interviews, contradictions, and other interesting aspects (Saunders et al., 2016, p. 576). These summaries provided the initial starting point for the findings chapter. Research notebooks and reflective diaries were used throughout the entire process and later transformed into the methodology chapter (Saunders et al., 2016, p. 578).

3.7 Quality of the Research Design

Saunders et al. (2016, p. 204-205) explains that reliability and validity, the criteria used to assess quantitative research, are philosophically and technically inappropriate for qualitative research (p. 204-205). Case studies, like this one, are impossible to reconstruct since they are snapshots of socially constructed interpretations at a particular place and time. For qualitative studies, different criteria were proposed, namely dependability, credibility, and transferability.

Dependability resembles reliability and thus the replicability of a study, results, and conclusions (Saunders et al., 2016, p. 206). The interview guide was developed in advance and included all the important topics to be discussed so secure a structured approach. The participants were also informed about these topics in advance to better prepare themselves and their answers. Although changes were made to the interview guide, and questions were added depending on the evolution of the interview, these changes were only minor and a technique to better understand the topics of discussion. Follow-up questions are also a well-established part of the semi-structured interviews approach. This thesis therefore has a high degree of dependability.

Credibility resembles internal validity and to what degree one can be certain the participant said what he/she intended (Saunders et al., 2016, p. 206). Before each interview, the respondents were informed about the purpose and intention of the research project. They also received the discussion topics and questions in advance to be prepared and gather any necessary information on less familiar areas. The companies also picked the respondents they deemed best suited to answer the questions. Sharing the questions in advance furthermore reduced the probability of introducing interviewer bias from my non-verbal and unintentional behaviour as a researcher. On my part, before the interview and to reduce the impact of interviewee bias, I prepared extensively by reading up on research and the companies. Additionally, all interviews were recorded to have the exact responses, phrasing, tone of voice, and other non-verbal ques available during the coding and analysis stages. The voice recordings were frequently used during the transcription phase and were replayed several times to make sure every subtle nuance was accurately transcribed and interpreted. Therefore, there is high credibility in this study.

Transferability is a parallel criterion to that of external validity or generalisability (Saunders et al., 2016, p. 206). To the best of my capabilities, I have provided all necessary information needed to conduct the same research again, from the sample collection criteria and the email initiating contact to the procedures of conducting, transcribing, and coding the interviews (Appendix 2 and 4). The only pieces missing are the interview transcripts, which, in compliance

with confidentiality, anonymity, and data protection, cannot and should not be provided. The information in this chapter and the appendixes should however suffice to replicate this study, and there is therefore high transferability, unless business contexts changes significantly.

3.8 Ethical Concerns

Saunders et. Al (p. 243-245) listed several ethical principles to consider when conducting research. Those have been central to methodological choices and decisions throughout the project. By clearly stating the purpose of the research project in the initial contact email, explaining how data will be treated, and by asking clarifying questions during the interviews, I satisfy the integrity and objectivity principles of the researcher (Saunders et al., 2016, p. 243). In addition, the general terms and conditions were attached to the email (Appendix 2 on "ethics and consent", and Appendix 3).

At the beginning of each interview, the same terms and conditions were read aloud to the participants to make sure they were understood. At the end of each interview, they respondents were also given the opportunity to ask questions, clarify their opinions and views on the topics, or add anything they felt was missing in the interview (Saunders et al., 2016, p. 251). Additionally, I as a researcher tried my best to remain open-minded, neutral, and positive in my questions, body language, and responses not to cause any harm or discomfort. The principles of respect for others, and informed consent of those taking place, were therefore satisfied (Saunders et al., 2016, p. 244). So too were the principles of avoidance of harm and non-maleficence, as the respondents knew their rights and that they could drop out of the project at any time (Saunders et al., 2016, p. 243). Letting the companies decide whether and who would respond, and informing them about the right to withdraw, satisfies the principle of voluntary nature of participation and the right to withdraw (Saunders et al., 2016, pp. 244). The respondents were given the final draft of the thesis to ensure they were accurately represented and properly anonymized before publication.

To secure data confidentiality and anonymity, each interview was coded and tagged with file names like "interview 1", "interview 2", and "interview 3" to keep it confidential, non-attributable and so it made sense to me as a researcher only (Saunders et al., 2016, pp. 244, 573). In this thesis, the respondents are cited using similar techniques, e.g. "I1" and "I2". Total anonymity can never be guaranteed, but all information was pseudonymized to the greatest extent possible. The files were stored in the NHH's secure cloud solution rather than on personal

devices to protect against information leakages in the case of theft or hacking. These measures were implemented to comply with the principles of informed consent, ensure confidentiality and anonymity of data, and to maintain responsibility in the analysis of data and reporting of findings (Saunders et al., 2016, p. 244). In an attempt to satisfy the principle of compliance in the management of data (Saunders et al., 2016, p. 245), I applied to the Norwegian organization Sikt for ethical clearance, explaining the research purpose, the data sample, how data would be stored, and how personal data would be protected during the project (Saunders et al., 2016, p. 55). Unfortunately, the attempt failed. However, after extensive email correspondence, neither Sikt, NHH, nor LSM found such an approval necessary to conduct this research (Appendix 5).

To the best of my knowledge and ability, no information is made up or altered, nor any results falsified. All findings are reported in full and accurately.

3.9 Summary Methodology

Table 4 clearly summarises the methodological decisions made in this thesis. The study is explorative, qualitative, inductive, and use semi-structured interviews and thematic analysis.

Methodological Decisions	
Research Purpose	Explorative
Data Collection and Analysis Method	Qualitative, Inductive
Research Strategy	Multiple Case Study
Data Collection Method	Semi-Structured Interviews
Data Analysis Method	Thematic Analysis

Table 4 Methodological Decisions

4. Findings

Now that we understand how the research was conducted, I will go through the findings of the interviews and develop a framework to explain the most important observations and the connections between them. This chapter forms the basis for the following discussion chapter, where the framework and findings will be discussed in the light of previous research. The current chapter is divided into five parts, each a component of the resulting framework. At the end of the chapter, the framework is presented as a conclusion. To distinguish between my use of systems and tools, systems consist of tools, but tools should be integrated with other tools to create a system. Ergo, a system is a larger and more complex concept.

4.1 Technology

To start off, all companies agreed technology had or could have positive benefits on SCRM. Furthermore, there exist numerous different kinds of technology and the companies varied widely in their level of digitalization, what tools they used, and how the tools were used. Digital tools and systems offer significant support for the risk management process: with analysis, and through the way this technology combines and compares data. More data can be stored, tracked, and accessed with the technology, to give a clearer picture of progress and development, both within the company, the market, and in the surrounding business environment. However, considerable amounts of manual work is still needed, both in data registration, decision-making, tracking developments, and risk reporting.

4.1.1 From Excel to Advanced Systems: Usage Patterns of SCRM Technology

The most striking observation was that although digital technology like Excel and SAP were common, each of the companies had their own systems and tools for SCRM and treated risks in slightly different ways. Some companies only used technology to a limited extent, while others had fully integrated systems taking care of, and tracking, both endogenous and exogenous risk factors. Another striking fact was interaction with and between digital systems. In some companies, employees were information bridges between different systems and gatekeepers of information, meaning they were responsible for analysing changes, plotting data and insights manually into the digital tools, and transfer information from one system to another

due to a lack of sufficient system integrations. "*We have to act as human bridges between data systems. This means we need to manually transfer quantities of goods, for example, from one system to another*" – I3. In other companies, the tools and systems interacted and information transfer between systems was automatic. The tools used also differed in their origin, ranging from in-house developments to standardized software bought from external providers. Independent of the source, some tool customization and configuration were always needed.

Tool complexity also varied greatly across companies. On the one hand, there was a company with an advanced pricing tool used for product pricing and coordination between business units operating under different market conditions. "*We have a pricing tool that is quite advanced (…) The purpose of this tool is to compare prices across all countries*" – I3. Coordinated pricing and a holistic pricing strategy reduced the risk of arbitrage between markets or unfavourable pricing terms for customers. Such advanced tools help companies better align with their strategy across their markets. However, the company admitted the tool did not yet work sufficiently. "*(..) it's not fully operational yet because not all [regions] are onboarded (…)*" – I3. To derive the full benefits of a tool, all regional units should be integrated. Also, to onboard all divisions, changes in processes are sometimes necessary. "*(…) we had to standardize our pricing structures first because in [countries], prices have historically been set in different ways*" – I3.

Despite the existence of advanced tools, Excel was commonly used, although its centrality of varied depending on the level of digitalization in the company. In a less digitalized company, Excel was the primary SCRM tool, used for contingency planning without distinguishing between the type of risk factor. "*(…) we actually use the same tool regardless of the risks we are managing, as long as it's within the supply chain. (…) for our supply chain, we actually only have Excel*" – I1. They had other tools for internal risk analysis, but Excel was their only SCRM tool. The respondent acknowledged the simplicity of their approach and expressed an interest in adopting new and more advanced technology, in the hope it could improve SCRM.

In the more digitalized companies, Excel was used alongside other systems in one of two observed scenarios. In the first, Excel remained as a legacy system although new solutions were developed and implemented. "*(…) we have continued using the old system and still rely on Excel*" – I2. In the second, Excel was integrated as a part of the system, but solely as a tool for data visualization and generating Power-BI report. "*(…) we have a visible Power BI report available to everyone, providing an overview of all the risk assessments that have been conducted*" – I7. Rather than being the only tool, Excel, in more digitalized companies, served to improve data readability. However, an interesting remark by a digitalized company was that

advanced tools not necessarily provide better functionalities than Excel. "*(…) we can view the graph ourselves in [advanced tool], but it's just as good as an Excel graph*" – I6.

There was also a relatively digitalized company with a self-developed tool, but they considered their tool an obstacle rather than a helpful resource. This was because it no longer aligned with their risk methodology. "*It's incredibly important for a tool to be relevant and have practical value; otherwise, there's no point in using it*" – I2. This had also been the conclusion of an external consultant assessing their supply chain risk management. Because the tool did not sufficiently align, risk managers and other employees did not understand the purpose of the tool. Rather than having any impact on SCRM activities, it was considered something they "had to do" and therefore not utilized to its full extent and, in some cases, even disregarded. To put it differently, the risk managers must perceive their tools worthwhile and helpful to use them. To improve SCRM, the tool must also be helpful and relevant, not only perceived as such.

> "*It doesn't help them in their work, and when a tool isn't perceived as relevant or useful—when it doesn't have a clear purpose—then it simply won't be used. People might feel forced to use it, but it won't have any real value. It becomes just an obligation rather than a tool that adds any benefit*" – I2

4.1.2 A Patchwork of Digital Technologies

I6 highlighted that no single solution solves all problem. Among the several tools on the market, only some, if any, satisfy the company needs and expectations. Different tools solve different problems, making a patchwork of tools necessary to address all problems. Instead of focusing on single tools, the company should elevate their focus and look holistically at digital technologies. To work properly, each tool requires individual implementation and configuration, but also integrations between the tools in the system are necessary.

Integrated systems and business units make enable access to information across several criteria, and combination of data for more complex analyses. For example, in company 3, it used to be hard structuring and analysing customer complaints for any meaningful insights. However, their new CRM system links complaints related to the same product, providing a more comprehensive and insightful view of the issue by incorporating information from various locations and points in time. With this CRM system, the company can now derive insights about the origins and development of issues, which enables more allocation of resources into more

targeted and efficient SCRM. For example, when a customer is calling, the number is connected to the CRM and all relevant information displayed on the screen, drastically reducing the time needed to help the customer. due to machine learning capabilities incorporate in the tool, it continuously improves with each interaction, enhancing its effectiveness over time.

On the flip side, these tools are expensive to both build, integrate, develop, and change. Given the high costs of development and integration, expectations and needs regarding a tool must be clearly defined before acquisition. If not, organizational changes and new requirements are instated on the tool, and new integrations must be built to satisfy the changing objectives. The higher the degree of customization, the higher the cost of replicating a complex system. It is therefore recommended that tools remain the same for the longest time possible, highlighting the need for clear objectives. Tools and systems may expand, or propagate, within a business and reach business units for which they were not initially configurated. This tool expansion was observed for both self-developed tools and tools provided by external software developers. "*It doesn't help to come in later and say, 'Well, that wasn't what I wanted' because that wasn't the intention when we started using the system either*" – I6. The tools and emerging systems must align closely with company strategy to secure their long-term relevance. To save costs and simplify implementations, an aim should be to minimize the number of tools.

> "*You really need to know and have a clear idea of what you want to achieve with the tool to succeed. I have personally never experienced a tool (...) that addresses all the problems in a company. You have to rely on several tools, so it's crucial to be very clear about your decisions and planning for a new system and what you want (...) The question is WHETHER there are good enough systems available to implement a solution that can handle multiple functions, allowing us to avoid the need to perform the same tasks for different parts of the process*" – I6

Some business processes are more central and critical than others, but building fully digitalized systems means digitalizing even the smaller processes and perspectives on the topic varied. The level of digitalization seemingly depended on company size. On the one hand, more digitalized companies highlighted the importance of also digitalizing small activities due to very high transaction volumes. Digitalizing even small, secondary systems could be provide significant returns. On the other hand, smaller companies mentioned that they had considered digitalization, but that the cost-benefit analysis was unfavourable and the project therefore not a priority. "*No, we don't have a proper system for that (...). We've actually chosen not to implement one*" – I5. One of the smaller and less digitalized companies noted that the cost of

the system outweighed the benefits for operational procurement activities, as they on only had a few contracts and sometimes no written contracts. "*(…) we haven't really seen the purpose of digitizing that particular process*" – I1.

In addition, larger companies have more resources, in absolute terms, to develop digital solutions. In this context, I2 expressed an altruistic perspective, suggesting large and specialized companies should take on the role as forerunners in tool development. These companies not only have greater resources at their disposal but also stand to gain more in financial terms from such advancements. The same logic applies to companies specializing in certain processes compared companies to those where the processes are secondary. I6 offered a different yet related perspective on technology propagation within the supply chain, emphasizing the role of large companies in driving digitalization. When a large company updates its systems and data inputs, it often sets requirements for its customers and suppliers to align with the new systems and provide data in specific formats. To maintain the partnership, smaller companies are compelled to adapt by updating their own systems. In other words, the larger company creates a higher demand for digital solutions, as smaller companies risk losing the partnership if they fail to comply. Since companies with limited technology and weak risk management can create vulnerabilities across both the upstream and downstream supply chains, this pressure to adapt ultimately strengthens the overall supply chain. A chain is only as strong as its weakest link.

> *It's not just about us being self-important, as some might perceive, but simply because our system does not accept old ways of doing things. We have to impose requirements, and that part of the process must be made more efficient, that's just the way it is. Some aspects are so critical that we cannot enter into any agreements unless they are in place because it won't work in our system. I also hope this is embraced and spreads further throughout the industry*" – I6

4.2 Effects of Technology

The reason companies choose to implement different kinds of technology, is the expectation of deriving benefits from the technology, some kind of effect on SCRM. In this part, these effects, or benefits if you like, will be more thoroughly examined.

4.2.1 Enhanced Data Management: Triangulation, Visibility, and Accessibility

Technologies can significantly impact processes and even change how risk managers and the company perceive and manage information. One respondent explained how introducing a digital tool improved data management. Tasks became more efficient, workflows were streamlined, and the focus shifted to higher-quality, goal-oriented data management. Although the tool enhanced data processing, it did not define its purpose. It remains the job of risk managers to develop clear strategies on what, how, when, and why technology should be used in SCRM, but they must also ensure alignment with company objectives. "*(...) the tools are more like data processing tools in my opinion, but we have to know ourselves what to do with them and how far we should go in processing the data*" – I6.

One company explained how digital technologies help them keep track of transactional data, what inputs are involved in the production of what output, to keep detailed lists of data for better compliance with rules, and for easier tracking of products through the supply chain if quality issues occur. Through this system, quality risks can similarly be traced from the customer all the way back to the factors of production, the specific suppliers, and the exact batch number from the supplier. This reduces the time needed to process customer complaints and inquiries. Good data management also assists in finding the source of errors, explain differences between forecasted and realised results, and eases monitoring and processes control. Digital technology allows greater accessibility and availability to data, enabling centralized data management for better SCRM and assistance in decision-making.

Several companies reported having multiple information points, from raw material procurement to final sales and the end customer. However, some expressed a desire for more transparency with customers and suppliers for a deeper understanding of risk factors in the supply chain. While some information points are under company control, others are external and managed by suppliers, transportation providers, or customers. Data collection from these strategic information points in the supply chain enables triangulation of issues. If there is a mismatch in the information retrieved from different sources, it indicates a potential issue, is flagged and

treated effectively with minimal efforts. The more information available, the deeper the insights and understanding of issues, highlighting the need for information sharing.

One company had encountered several situations where supply chain parties behaved opportunistically, or misreported data, to save their reputation and profit margins. Opportunistic behaviour can be hard to detect, but through data from customers and other supply chain partners, they were able to triangulate the problem, develop strategies for managing the situation, and could directly confront the player. Without triangulation, finding the source of the problem can be very costly and unprofitable. In other words, triangulation reduces the possibility and risk of opportunistic behaviour by both suppliers and customers.

> "*Then it might happen that a driver claims, "Yes, it was delivered at such and such a time" to protect their statistics. But in reality, it wasn't! The customer might say, "No, I haven't received the goods; they haven't arrived yet." These are the kinds of issues we can catch by maintaining communication with the customers at the receiving end*" – I3

By tracking information about the in-house production and market changes, and comparing the insights to forecasts, companies can adjust production more effectively to manage market changes or unexpected demand trends. Sales strategies can be modified to avoid the risk of stock-outs. Tracing developments in central KPIs helps mitigate demand risks and reduces the time needed to implement reactive responses in the case of emerging issues.

> "*Sometimes, it's necessary to slow things down. You might have sold more than what's available in the warehouse. So, we need to take a step back. It's great to sell, but maybe we should focus on selling something else that we already have in stock because we're creating some issues for ourselves here*" – I3

Digital technologies furthermore facilitate easier data access from more locations. Increased availability and accessibility of information is beneficial because more people are informed and updated on important issues. One of the respondents explained that "*if I get sick or am absent, everything comes to a halt here. Simply put, there's no one who can take over immediately because I'm the only one who has that knowledge*". Compared to human gatekeepers of information, digital solutions can increase process efficiency and reduce risk exposure. However, another company highlighted the potential downsides of overly broad access, emphasizing the need to restrict access to sensitive information. "*There have been quite a few instances I've encountered where sensitive information has been leaked*" – I6. Sensitive information, if leaked, could severely harm a company. The more people with access to

sensitive information, the higher the risk of information leakage. Access should therefore be granted only to a limited group of people. "*Some of the really sensitive information, such as supplier agreements, is at least kept internally within the head office*" – I6. Training employees on proper data management prevents such information leakages but is no guarantee. Within digital systems, different levels of access should be granted given the role of the employee in the company, but this is the area of Information Security Management. "*There are different levels of access to agreements, with several tiers in place to ensure that truly sensitive information does not get leaked*" – I6. We can conclude that better access and availability of information is beneficial, except for cases involving sensitive information.

4.2.2 Higher Data quality

High data quality is a necessity to derive deep and reliable insights from data. "*The most important thing is that the data entered—the data we work with—is as accurate as possible. It's crucial to ensure the quality of those numbers because, as they say, "garbage in, garbage out.""* – I3. With the introduction of digital tools, I6 experienced higher data quality, though much of the data processing and usage remained manual. "*It is used for data collection, so it improves data quality, but the actual data processing and usage is manual work*" – I6. I3 explained that low-quality and unreliable information on stock, demand forecasts, and upcoming deliveries increased the risk of stockouts, delivery problems, and lost sales. The impact of information risk further depended on the product type, sourcing destination, and lead time. "*The longer the distance from production to warehouse, the more sensitive the situation becomes. (...) If stock starts running out now, it's a huge problem—we know it will take a quarter to resolve. Naturally, this requires stricter control. However, if a product is manufactured at a facility adjacent to the warehouse, where the warehouse is just next door, it's not as critical*" – I3.

4.2.3 Improved Collaboration and Communication to Coordinate Efforts

Better data collection, analysis, and management provides a better foundation when seeking new collaborations and B2B partnerships. With deeper insights derived from digital technology, a higher degree of transparency is possible with suppliers and customers. Transparency with supply chain partners might lead to better coordination and total results from SCRM efforts.

When sharing data and insights with the supply chain, there is a higher likelihood of risks being correctly identified, analysed, and mitigated in advance of events, but also better coordination.

> "*Yes, yes, and it also provides better groundwork for when we look for a new collaboration with another supplier next time. We can be more professional and provide better data. And also, we can be transparent with our suppliers. We see a risk here; what are YOU doing about IT? Then we can have a dialogue about that*" – I1

Risks propagate through the supply chain, and it is therefore important that suppliers and customers have the same understanding of the risk landscape and coordinate their efforts. To save time and resources on risk communication, it is important to know the interests and pain points of supply chain partners. Communicating everything related to risk management could be a waste of time and resources: for the sending part because it takes time to create and prepare the reports, and for the receiving part because they may drown in information and not distinguish the most the important and relevant information. Risk reporting in the supply chain should be customized to the receiver, but so too should internally reporting. I2 said that "*through the management team, we present the most important risks to the board*", which meant the board should only receive the information relevant to their level of decision-making, in other words tailored to their aggregation level of company concerns. Similarly, customers should receive only information on the risks which concern them the most. Targeted risk communication is the most resource efficient but requires clear definitions on each party's needs.

Furthermore, the supply chain is integrated through digital systems. Both suppliers and customers receive updates as soon orders are registered or their status change, but there is a large need for better information flow with the customers. With better information, as I5 explained, suppliers can improve the quality of their services for both their direct customers and the end customers. Close dialogue and collaboration with customers and suppliers, was a frequently used strategy to highlight potential risks and share information among the different companies of the supply chain. I3 told that "*[we] have close dialogues with our transporters (…) we meet with them to check the status, how things are going. We also have quality reports that we deliver*". Another important strategy used by was to gradually develop the relationship with new suppliers, increasing volumes as they grew confident with the new supplier over time. It allows the company to monitor the suppliers and their behaviour but give the suppliers time to learn what the company expects and to adapt according to these expectations.

An interesting observation of company 3 was the information sharing between them and their supply chain partners. By collecting all the information about the supply chain in a single CRM, the company could (1) predict future demand through patterns about end customers obtained over time in the system, (2) detect miscellaneous and opportunistic behaviour, or overoptimistic procurers that try securing a supply of critical and hard-to-get products through higher-than-necessary order volumes, and (3) help end customers with inquiries despite there being several companies in-between. If order quantities significantly exceed the predicted demand, the managers are alerted and the customer contacted to better understand the cause. This detection system protects the company against demand shocks. Additionally, through access to information about the various parts of the supply chain, demand side uncertainty is reduced because downstream companies and end-users obtain important and relevant information.

4.2.4 Real-Time Information for Shorter Response Times

> "*People have been working with paper slips that need to be registered (…) This creates a backlog, and our customer service team doesn't always have fully updated data. This can lead to discrepancies, such as saying we have stock available, only to discover that it was already loaded onto a truck earlier in the day*" – I5

A central benefit about digital tools and systems are real-time updates. Data collection from different parts of the supply chain allows continuous monitoring, and risk managers are immediately alerted when parameter values exceed acceptable levels, thereby enabling the company to act already at the early stages of a disruption. Several companies frequently compared stock levels and production volumes with their forecasts and demand orders to track market developments. "*The system, in terms of forecasting, immediately notifies us if inventory starts dipping below a certain volume threshold*" – I3. If there are any discrepancies, where and demand forecasts or demand orders exceeded planned production, stock level, or deliveries, the difference is measured against a threshold value, in what resembled a traffic light system, to determine criticality. If the values surpass the acceptable value, risk managers are involved and prompted to act. The more digitalized companies had developed systems based on the principles of continuous monitoring and risk identification, with prognosis and forecasts were updated daily. In contrast, one of the less digitalized companies expressed a need for more updated information on stock levels, which had caused backlog issues in the past. "*It's about having more real-time recording, or simply having actual measurements, right? Not just approximate*

inventory values and stock status, but actually being precise" – I5. Real-time data is praised by those having it and sought by those lacking it, therefore being a clear benefit of technology.

4.2.5 Increased Profits, Bargaining Power, and Competitive Advantages

One of the reasons companies digitalize processes is to improve efficiency and effectiveness, thereby reducing costs and increasing profits in the long run. However, digitalization projects consume a lot of time and resources during their development and implementation, which could be a deterring factor for some companies. For example, I3 admitted that although a project had been going on for some time, the foreshadowed cost savings had not yet materialized due to the high initial investment costs. "*We haven't seen any savings yet, but I'm confident that once everything is in place, those savings will come*" – I3. Before the benefits materialize, all system integrations and configuration must first be done. For small companies with limited budgets, the time and resources allocation needed can be overwhelming or unsustainable short-term.

However, I3 was positive that the digitalization project would be profitable in the long run. They were also positive regarding the long-term goal of incorporating all their regional offices into the system. With the same platform, they explained that regional offices would be able to align their strategies and processes, thereby enhancing efficiency and profitability across the company and markets. This unification would further strengthen their collective bargaining position in negotiations with suppliers and customers through aggregated volumes, but also reduce transaction and procurement costs, increase revenues, and other benefits derived from economies of scale and scope. An all-encompassing platform will also improve their control of internal processes through a comprehensive view of all their logistics across Europe. "*Those are the types of things that will definitely give us some advantages with the system in the future. But right now? No, it hasn't provided any yet*" – I3. Generally speaking, it can be concluded that digital technologies may provide competitive advantages, especially in the long run.

4.3 SCRM

In this part I will delve into the applications of technology in SCRM and explain how the beneficial effects mentioned in the previous part improve SCRM.

4.3.1 Different Perspectives on and Approaches to SCRM

Most companies clearly differentiated the upstream supply chain from the downstream supply chain, generally perceiving the "supply chain" as all activities preceding their own production, while the downstream supply chain was a responsibility of the sales and marketing departments. There was a clear division between the procurement, sales, and marketing teams. Sometimes, objectives differed across the departments, causing risks of misalignment between stock levels, production, and demand, necessitating intervention to avoid stockout. This clear distinction also makes a holistic SCRM approach to close to impossible.

Although the companies operated within diverse supply chain structures and industries, they struggled with many of the same or similar supply chain issues. These included pricing and the cost of supplier's products, the access and supply to raw materials, monitoring of risk values, and market changes. Companies differed in their SCRM focus, from correctly conducting all stages of the process to a more practical concern about applying technical solutions to solve supply chain issues. Some of the companies had fully developed SCRM philosophies.

4.3.2 Proactive and Reactive SCRM

According to I1, digital tools and systems can make SCRM more proactive. Some risks are hard to identify, and only identified after materialization, whereas others "*are very obvious, so you can take concrete actions before they happen*". For the second group, countermeasures were implemented before the risks materialized, drastically reducing the criticality of the risk factor. In other words, the degree to which a company is proactive depends on the nature of the risks they face and how early risk managers are informed about disruptions. I2 outlined two possible approaches to proactive risk management: "*(1) reducing the likelihood of them occurring or (2) by taking preventive measures so that the consequences are minimized if they do happen*".

In general, reactive strategies were most common and a central concern was what the company should do if and when various risks materialize. This approach resembles contingency planning:

"*it often has to be simple enough that you can create a plan in advance... Like, how do we handle it if there's a new supplier? You've already considered that early on, thinking about how to manage such a situation*" – I7. Some risks are hard to identify and assess in advance, and therefore materialize without the companies having developed contingency plans for counteracting them. Then again, risks can be too hard or expensive to mitigate or fall outside company influence. "*It is indeed difficult to have a plan B for every radical event that might occur (...) Some risks must be accepted and lived with*" – I1. Both proactive and reactive SCRM strategies are consequently limited by the means and abilities of the company.

> "*There may be specific situations where risks are simply beyond our control or authority to address. These risks just exist and can pose a threat to us. We might need to keep them in mind, even though they are far outside of Norway's borders or deep within our supply chain. We just have to stay aware of them without being able to take concrete actions*" – I2

4.3.3 Risk Identification

With the integration of digital tools, it is hard to distinguish between risk monitoring and identification. By constantly monitoring company processes, market developments, suppliers, customers, and other supply chain related aspects, deviations and anomalies are easier detected. If values exceed acceptable thresholds, they are automatically flagged to catch the attention of risk managers. Data visualization, in the form of colour coding values according to criticality, is often implemented to assist risk managers through increased readability. Colour coding also help distinguishing between existing problems and what may become problems. "*We use the traffic light model, so what has a problem is marked red, and what is starting to become a problem is marked yellow*" – I3. Risk identification and risk monitoring merge because the continuous monitoring enables detection of trends. By comparing the identified risks with threshold values in the traffic light system, this approach also incorporates risk assessment.

However, the performance of digital technologies depends on the risk and there are two categories: (1) slow development, and (2) rapid development. When risks develop slowly, the systems can easily detect these changes, alert risk managers, and track the changes closely. For these risks, digital tools are very helpful. Unfortunately, not all risks behave like this. Some risks materialize rapidly and without warning, sometimes with severe impacts on the company, supply chain, or business environment. "*Things like COVID, which came in 2020, were such a*

massive, massive event that had a big impact on us, but something we didn't foresee. We weren't prepared for it" – I2. Identification systems are less helpful in managing these risks because there is too little data available to identify any trends in the data. Also, the reliability of the analysis diminishes the less data is available. "*So covid is a typical example where the forecast didn't help us much because something very unexpected happened. But the traffic light model works well when the volumes fluctuate normally up and down*" – I3.

In some companies, the identification phase was mostly manually and based upon collective brainstorming or personal experiences of the risk managers. Although this method is more extensive in the time and resources needed, it could improve risk identification and complement digital risk identification. "*You will still have manual work when it comes to identifying the risks that exist and coming up with measures to reduce the risk*" – I2. Manual risk identification is better suited for identifying risks of the second category. There are, however, major limitations to manual risk identification: it relies on the knowledge and experience of the risk managers, is affected by emotion, subjective judgements, biases, culture, language, and tacit knowledge. The process is also limited by the imagination and effort of the managers. "*Things are done differently, and some people put varying amounts of energy and effort into it. And perhaps, they do not always make fully adequate assessments*" – I2. Manual risk identification complement that of digital systems, but also introduce uncertainties an information risks.

In supply chains, information risk is a central risk factor due to the need for high-quality and reliable data in the supply chain. One way to deal with this risk is through strategic information points along throughout the supply chain to enable triangulation (see 4.2.1 for a more elaborate discussion). In company 3, timely delivery, delivery volume, and product damages were among the variables constantly tracked and compared across several information points to ensure data reliability. Monthly meetings were then held with suppliers and customers to ensure the information flow, coordinate efforts, and solve emerging issues. This kind of system is however heavily dependent on reliable and enough data as was explained earlier.

> ""*[We] hold monthly meetings with each transporter if they are above a certain size, where we review performance. [We] pull data from our systems to see how things look in terms of quality (…) If there's a mismatch, where the delivery isn't up to standard, or we see that quality has dropped below a certain level, those transporters are flagged. They are notified that we are monitoring them, and they are asked to explain and provide solutions*" – I3

4.3.4 Risk Assessment/Risk Analysis

There were large differences across the companies in how they conducted risk assessments. Some companies relied on manual labour for analysing, categorizing, and prioritizing risks, using traditional risk maps and risk matrices with criticality scores composed of impact and probability. There were guidelines to ensure consistent assessment, but some degree of subjectivity will always be present in manual assessments. "*(...) it is poorly described how the risks should be scored correctly. There is a lot of variation in how this is done*" – I2.

Digital tools help companies concentrate on the most important risk factors. Even in companies mainly relying on manual work or simple Excel models, the tools calculate risk values, rank the risks accordingly, and highlight criticality through colour coding. Risk factors were generally categorized as low, medium, or high. "*[The tool] is designed and used, I won't say by everyone, but a good number of project managers use [the tool] to identify risks at the start of a project and to score them in terms of whether they are high, medium, or low risks*" – I2. Risk identification alone is not sufficient. The company also needs a clear picture on the criticality of different factors – the likelihood of materialization, and the impact. Digital technologies help a company stay vigilant by providing updated insights on how risk criticality values develop over time. With a clear focus on which risks are the most critical, the company can better target their SCRM efforts for improved reactive and proactive strategies.

> "*Today's system is completely manual, really. (...) Yes, I feel the system contributes to better Supply Chain Risk Management, and it has led to decisions that have made us less sensitive. The scenarios we have set up in advance have actually occurred. And then we have had redundancy. (...) So this has made the system more robust, more predictable, and more stable. This is important because we have worked with risk analyses to identify risks before they arise*" – I1

Digital tools can also manage more variables and risk factors simultaneously compared to humans, thereby providing a richer and more complex understanding of the nature of each risk. More aspects about the risk environment will therefore be included in the analysis, enabling a more holistic approach and models of higher explanatory power. Additional factors considered can include the time needed to switch to alternative suppliers or the impact of/on revenue. In one company, even the lack of clear mitigation strategies for some risk factors was considered, which then translated into higher criticality values. *"Currently, we have no preventive measures or alternatives, so there is nothing in place here. This results in a high risk value. Therefore, we*

take actions" – I1. Computers also do more advanced calculations faster, but the companies complained about the digital solutions not being preprogrammed when they were bought, but that they had to configure the tools themselves manually before they started working.

4.3.5 Risk Mitigation

Informants described that in most cases, digital technologies provide little or no direct help in risk mitigation. One company explained how their digital tool was frequently used to identify and assess risk, but that "*it falls short in terms of risk-reducing measures*" – I2. Across the companies, no tool was identified that itself conducted risk mitigation or implemented mitigation strategies to avoid disruptions. In other words, there is a large room for improvement within this area. In the most advanced cases risk managers were still the ones making the final decision, but the tools and systems provided recommendations, insights through digitalized data analysis, and/or directed attention towards problems. Put differently, the systems do not mitigate the risks but rather improve the efficiency of the risk managers. I3 provided an example on how comparing current stock levels and planned future deliveries with demand forecasts provided a clear picture of the ability to meet future demand, thereby offering early warnings about potential demand and supply risks. Real-time data and early warnings allowed the company to act in the early stages of the risk event. With early risk identification, more time is available to solve the issue, contain its scope and scale, which in turn reduces the severity of the impact.

> "*And it's often like this: we're not completely out of stock, but we start noticing a trend where we're dipping into our own inventory. (...) So, when we foresee a problem two months down the line, there's something we can do. We often have variants of our products, which allows us to steer the customer from one product to a similar one. (...) Just small things like that—minor adjustments that are being made continuously*" – I3

Tools and systems can also assist risk mitigation by assessing the effect of implemented mitigation strategies. Once risks are identified, assessed, and mitigation strategies implemented, their criticality level should be monitored. If the risks remain critical over time, it is an indicator that the implemented mitigation strategies must be adjusted or changed. "*Measures that do not have any effect are unacceptable; if a measure has been implemented three times without results, we will challenge them in the next reporting. Is this the right measure? Are there other options?*" – I2. In simpler terms, the digital tools and systems can indirectly detect weaknesses in the current risk mitigation process and thereby improve the SCRM quality and effectiveness

in the next period. One company noted that before they started monitoring the development in criticality, risk mitigation had a tendency to stagnate because ineffective mitigation strategies were recycled and reapplied in period after period rather than changed and improved.

4.3.6 Risk Monitoring

Digital technologies can be used to monitor internal production, the market, suppliers, customers, demand and supply shifts, among other things. Thereby, trends and movements in the market can be easier spotted Also, the company can adjust processes, focus, target areas of peculiar interest, and/or evaluate processes. Through digital tools, it is easier to stay updated on the production plan and to what extent the company manages to follow it. Using timestamps on the continuous data updates, a company can tell at what time a trend or risk factor emerged, but also track the development over time. Combined with triangulation, a company can determine the exact place and time of a risk event, or closely follow the speed of propagation through the supply chain. This allows the company to easily and quickly understand the root causes and triggers of the risks, their nature, but also the propagation pattern of risks in the supply chain.

However, there is room for improvement here too. Some monitoring tools are of poor quality and do not offer the full range of analytical functionalities companies may need. One respondent expressed frustration over the lack of alternatives for conducting technical analysis on market trends and used the example of simple candlestick charts, an analysis tools commonly used in finance to track price developments of financial assets. Instead, the risk manager had to interpret graphs manually and depended heavily on personal experience and subjective judgement.

> "*We have the models as a foundation for understanding how trends develop, which is why I find it unfortunate that we have such a basic graph setup. For example, in the stock market, it's very common to use candlestick charts. These make it much easier to visualize trends, which we currently lack. With our setup, you need experience and the ability to interpret a graph to make an assessment*" – I6

4.3.7 Integrating and Automating SCRM Processes

Through digital technologies and integrated systems, the phases of the risk management process merge. Rather than conducting risk identification, assessment, and monitoring as separate phases, their distinctions disappear and they become seamlessly integrated and simultaneous. The system tracks developments of key performance indicators (monitoring), detects significant changes (identification), compares the changes to predefined parameters (assessment), and flags the deviations if they are significant. By drawing the attention of the risk manager towards the most critical developments, more timely and targeted mitigation efforts are possible. The last step of flagging and catching the risk manager's attention can be viewed as a new intermediary step, differentiating traditional and manual SCRM from digital SCRM.

However, there is room for improvement on the mitigation phase as it depends on involving risk managers, but the degree of involvement differs between systems. Some systems propose mitigation strategies based on criticality and the kind of risk. These could include alternative sourcing locations or tapping into the stock of other regions in larger companies with multiple warehouses. The role of the risk manager was to assess and approve of the strategies, or to update or change the propositions when the recommendations are outdated. Digital tools are however stupid and do not comprehend the context or causes of deviations and patterns in the data. For example, I3 explained how filling the backlog was registered as a demand shift, leading to the system proposing mitigation strategies like increasing, rescheduling, or outsourcing production, although the demand increase only existed on paper. Blindly following such a recommendation can in the worst case hurt the company or take capacity from products in actual demand. Most systems did however provide no such assistance. Ergo, risk managers are still important and a central part of SCRM despite the existence of advanced tools.

> "*it's not that smart because it makes suggestions, which is all well and good, but if you only followed it, you could end up with a forecast that's very wrong. For example, if we have a backorder situation, meaning we're out of stock, and we've had a situation where we simply haven't had goods for a while. When the backlog is filled, it shows a huge increase. But that's a demand that isn't from exactly that week or those two weeks, so the demand will drop, maybe even more than before, right*" – I3

4.4 Human and Systemic Obstacles for SCRM Technology

It must be stated that just procuring some SCRM technology does not automatically guarantee the companies obtain the promised effects of technology. This part is devoted to factors that may hinder or disrupt the realization of technology benefits, but also important drawbacks and concerns related to the technology. The list of factors influencing technology adoption and implementation is long, and only the most significant will be treated.

4.4.1 The Role of Humans in SCRM

As we have understood, the human component is still an integral part of SCRM, with several tasks and key activities conducted manually. The role of risk managers cannot, and should not, be overlooked. We have seen how employees function as gatekeepers of information and bridges between different systems, but also how they complement digital risk identification and need to configure and accept the purpose of technology, and the results from digitalized data analyses. Human judgement is also necessary to evaluate the recommendations provided by the more advanced digital tools as part of risk mitigation.

In one of the digitalized companies, the digital system provided reports, but the employees had actively to ask and specify what reports the wanted. There was no automatic analysis or risk reporting. "*There's no automatic process where a report comes out and flags that there's a problem, but we generate active reports*" – I3. Similarly, there are differences in the kinds of tools that exists. Even within the more digitalized companies, parameters had to be specified manually provided before the system alerts the risk managers of any changes.

> "*But there is nothing in relation to 'be careful, you might run out of this or that.' It doesn't provide that. We have to set it up as an alert based on the data we want it to pick up, with specific thresholds. It doesn't make that assessment on its own. (…) It depends on what we consider to be risks for our supply chain. If it's important to have goods in stock, then okay, that is a risk. We need to set up alerts with the thresholds we think are appropriate. It is certainly possible to do that, but we have to identify it ourselves*" – I6

Although some of the customer and supplier communication could be replaced by digital tools and systems, it is not necessarily desired. There is no reason to switch just because there is a digital version of something. Implementing digital technologies to replace humans may in fact erode relational capital and harm the company. "*A weakness can be that we remove some of the*

human element that has been there, like the close contact with customers, for example. The more automated we become, the fewer human touchpoints there are with customers" – I3. Another area where human competency is invaluable compared to machines, is in customer and supplier interactions. Deep connections built over time between humans are irreplaceable by machines and can be considered a competitive advantage.

> "*This closeness means that problem-solving and such go very quickly. You get to know each other very well, and I see that as an advantage because our customers might automatically want to choose us because they think, 'Well, they are nice and always so helpful, and they fix all problems right away"*" – I3

However, involving humans in decision-making introduces the risk of human error, subjectivity and biases, emotional responses, limited processing capacity, and opportunistic behaviours. For example, I2 explained the importance of leadership involvement to motivate risk managers and make them execute their tasks correctly. Similarly, the risk managers needed to subjectively perceive the SCRM tools relevant to implement them in processes.

4.4.2 Technological Issues

The period surrounding system updates and changes could be problematic for a company and introduce risks as it takes time for new systems to fully implemented. The staff must be trained on how to use the new system, and important information might be stored in the old system without any efficient solutions for transfer to the new system. The new system could also contain bugs. In one of the companies, the digital system had been down for more than half a year because of a transition from one category structure to another. They received error messages and had to reconfigure the tool. At the same time, historic data was left in the old system and had to be manually plotted into the new system. This process consumed a lot of time and resources and was therefore deprioritized in favour of more important projects, but then led to valuable information and insights being lost. In another company, a new and old version of the same tool were not compatible, and it created a divide among business units because some continued using the old system whereas others switched to the new system. Communication between the units because a problem and caused situations of misalignment between the units. Before the new version of the system was rolled out in the entire company, the employees had themselves to bridge the gap between the two versions.

Another challenge when integrating systems is that even minor and seemingly insignificant components can cause significant issues, as all parts of the system must be integrated and communicate with each other for the system to function properly. "*This software then needs to communicate with [company system], which we use in the factory to adjust everything related to the conveyor belts and the flow in the factory. That, in turn, has to talk to SAP because the orders come from SAP*" – I3. Tools are often very small and only apply to a small part of the process, but as I3 explained, even the tiniest parts of the system, like a robotic arm, can bring down the entire system if not properly integrated or configurated. "*(…) it can break everything. If it doesn't work as it should, the entire factory and warehouse come to a halt*" – I3. The larger and more complex the system, the higher the probability for some part breaking down.

The optimal solution would, therefore, be a minimalistic system design with the fewest tools possible to limit the number of required integrations. However, a recurring theme across the interviews was that the tools and systems available on the market did not always offer the right or sufficient functionalities. Despite the growing need for digital solutions, the market does not yet offer tools that fully satisfy all company needs. One company also raised concerns about digital tools failing to incorporate insights from published research in the field, noting that while there is valuable research available, it is often overlooked in tool development. The alternatives to purchasing a tool were either developing an in-house solution, a costly process, relying on manual work or adapting company processes to fit the tool. Most companies facing this dilemma chose to delay their decisions, opting instead to continue with manual work or legacy systems. One company attempted to standardize its business processes to better align with the tool, hoping to reduce the costs of future system updates. However, implementing these changes proved more challenging than anticipated, leading the company to abandon the project and instead customize the tool. It is therefore questionable whether it actually is easier and cheaper.

4.5 Moderators Between Effects of Technology and SCRM

Even when the technology is correctly implemented, both internal and external factors could obstruct the technology form improving SCRM. In spite of successful implementation, the aggregate risk and criticality levels may remain the same or even increase. Reasons can be found at four different aggregation levels: (1) environment, (2) market and industry, (3) supply chain, and (4) company. A fifth "individual" level, can also be argued, given the role of humans within SCRM. This has already been thoroughly discussed earlier parts and is therefore not included here. Future research might consider including this level by synthesizing prior discussions. In this analysis, levels 1 and 2, but also 3 and 4, are treated together.

4.5.1 Environmental and Market Factors

All the companies noted that geopolitical changes in recent years have changed the risk environment of global supply chains. "*(...) our risk landscape has been evolving and is continuously developing*" – I2. The focus has changed, and companies are now more aware of the possibility of similar disruptive events, as if the probability increased. "*(...) with the war in Ukraine, even though it hasn't directly affected us, it has at least made us start thinking about these kinds of things*" – I2. Geopolitical turmoil has demonstrated such events were possible, leading companies to pay closer attention to areas of their supply chains previously overlooked. "*It wasn't relevant or seemed so unlikely, but suddenly things have happened that could have enormous consequences—things that were unthinkable before*" – I2. The unimaginable suddenly became a reality, turning the risk perceptions of companies upside down.

The increased possibility of risk events is one thing, but also the rules and market dynamics changed. For instance, significant changes occurred when central actors decided to change their behaviour, adopt protectionist policies, and restrict supply through trade barriers. China was one such actor, a world leading raw material supplier and manufacturer. During covid, they suddenly decided no longer to supply international markets of a central product, and event drastically increasing the price. Companies unable to pay the higher price were pushed out of the market. "*They just cut off contact one day and said that they would not sell anymore. They will keep it in China. It created a significant impact, affecting prices greatly (...) Fortunately, the entire market felt this, so it wasn't just us who were affected*" – I3. A comparable event was the outbreak of the war in Ukraine, which led to the reallocation of materials toward weapons manufacturing. In this scenario, there was a demand shift rather than supply shift, with new

market entrants competing for the same materials. The result was the same – a price increase. "*A lot of what was produced suddenly went into war production. (…) Consequently, the demand for this material increased significantly, and military contracts offered better pay, leading the civilian market to opt to sell their supplies to the military instead of to us, who needed it for our [products]*" – I3. Company 3, providing hand sanitation and face masks, experienced similar demand shocks for their own products during the pandemic.

Other events have had specific impacts on particular risks, such as logistic risks. Due to a relative wage increase for truck drivers in Poland, there was a shortage of truck drivers. "*For many years, we were fortunate to have drivers from these countries, but they have chosen to return home because salaries and living conditions have aligned in a way that made it feasible for them to do so*" – I3. Truck drivers are central in distribution and are sometimes the only way of transporting products from factories to the warehouses or from warehouses to customers. The shortage therefore created significant bottlenecks in the supply chain, drove up freight rates, and increased the supply risk of not reaching the end customers. Similarly, important trade routes have been affected, and even blocked, translating to longer lead times, uncertain delivery times, more pipeline stock in the supply chain, and a higher risk of something happening to the products during shipment. "*It can be both that there are delays because they often have to drive around [problematic area] to get to us, and then we might be out of stock for that item*" – I4.

Depending on the market and the characteristics of supply and demand dynamics, risks fluctuate in cyclical patterns. Although those patterns can be somewhat predicted, there is little the company can do to prevent those risks. "*There are significant economic fluctuations in our industry, and we have been in business since [year], so we are familiar with the ups and downs. There was a very high peak, but we know that a significant downturn follows*" – I5. Negative price changes on the supply side translates into increased costs, whereas negative price changes on the demand side reduce revenues. Moreover, elasticities, exchange rates, and interest rates affect consumer behaviour, profitability, and the terms of international trade. Supply and demand shifts may not be devastating in their own, but added on top of the other changes, the sum might be overwhelming. Considering all the changes, the markets may also change.

> "*It's such an extreme situation because there's high demand for [material], not just from those who want the [material], but also due to a weak Norwegian krone, making it very attractive for [producers] to export the [material]. (…) The prices to end customers are low due to the poor market. So, we end up stuck in the middle (…) We're facing much higher input costs, but we're getting lower prices in the market*" – I5

4.5.2 Supply Chain and Company Factors

Supply chains differ in both the number, type, and complexity of links between the players. These factors affect the need for technology and what kind, what effects are practically obtainable from the technologies, and the technology performance. One company was vertically integrated, had only a handful suppliers, and was responsible for 90 % of the value creation in the supply chain. In contrast, another company had an intricate system with several levels of sub-suppliers and logistics providers. "(…) *just with third parties, it's almost fortunate. Sometimes there are even fourth and fifth parties where they have hired someone who hires someone again, so then we start talking advanced logistics*" – I3. The degree of globalization also matters. Global supply chains are exposed to more risk because of different juridical zones, governments, and trade regimes, different company practices and market dynamics, not to mention language and culture barriers. SCRM in complex and globalized supply chains have more to gain from digitalization in terms of efficiency.

Companies differ just as much in complexity and size as do supply chains. Among the interviewed companies, some were large multinationals, while others had only a few business units and operated primarily in Norway. There were also large differences in process maturity, company structures, and the degree of centralization within the companies. Misalignment between service centres, poor internal communication, and restricted information flow were main causes for operational risks that may be solved through more technology adoption.

4.6 Concluding Framework

To conclude this chapter, we again examine the research question "*how can the use of digital technologies improve supply chain risk management*". Like we saw in the first part of this chapter, there exist several different kinds of technology. To assist in choosing the correct technology, and to obtain the greatest effects, the purpose of the technology should be clearly defined in line with company strategies and SCRM objectives from the start. A patchwork of different technologies is oftentimes necessary to cover all supply chain related issues, but this might significantly increase the cost of implementation and therefore deter some companies.

In part three, we saw that digital tools were of assistance in both identifying, assessing, and drawing attention to critical risks. Technology also helps assessing the effect of mitigation strategies indirectly, thereby improving the effectiveness of SCRM in the long run.

Furthermore, digital tools assist decision-making, mostly through data analysis, data visualization, and real-time system alerts. Real-time updates, and constant tracking of market developments and inhouse production, draws the attention of risk managers towards the most critical risks, thereby ensuring necessary adjustments are made when the business environment changes. Deeper insights and data sharing also facilitates closer collaboration and joint SCRM in the supply chain. Leveraging digital technologies, it is possible to detect the exact time and place of a risk, which enables short response times and targeted efforts to mitigate and contain the risk at an early stage. Consequently, digital technology improves SCRM.

Figure 1 The Main Relationship

These improvements are however obtained through the functionalities and benefits provided by the technology, the focus in part two. These included more collected data, enhanced data quality and analysis, continuous monitoring of key KPIs, more transparency and information sharing, triangulation of problems, greater accessibility and availability of information across both the company and supply chain, and real-time updates. Data visualization was also integral to risk assessment for drawing the attention of risk managers.

Figure 2 The Effects of Technology as a Mediator

Adoption and implementation of the technology does not however guarantee the promised SCRM improvements. Through the three first parts, we saw how prerequisites like system integrations, customization of the tools, and the perceived relevance of the technology affected its utilization. Additionally, humans still play a significant role within SCRM and probably will in the coming years. Human-machine interactions, and to what degree risk managers can implement digital solutions and interpret their results, largely affect the extent to which SCRM is and actually can be improved. Completely replacing humans could also harm the SCRM process and the company as a whole if it erodes the competitive advantage of relational capital.

Another major limitation lies within the technology itself. The more complex and integrated a digital system, the harder it is to change. At the same time, the more integrated components are in the system, the more points of potential failure there are. If one of the components break

down, it could bring the whole system to a halt. I here refer to the examples of the robotic arm, changes in the category structure, and system upgrades. However, these lie within the area of Information Security Management and outside the scope of this research.

In addition, there are factors affecting the risk environment of a company independently of digital technologies. These may exist on the different aggregation levels of environment or market, be related to supply chain characteristics, or result from company characteristics. Regulatory changes and new trading routes, demand and supply shocks, economic factors like exchange rates and interest rates, market fluctuations, and supply chain complexity must all be considered when evaluating the effect of technology on SCRM not to misinterpret the results.

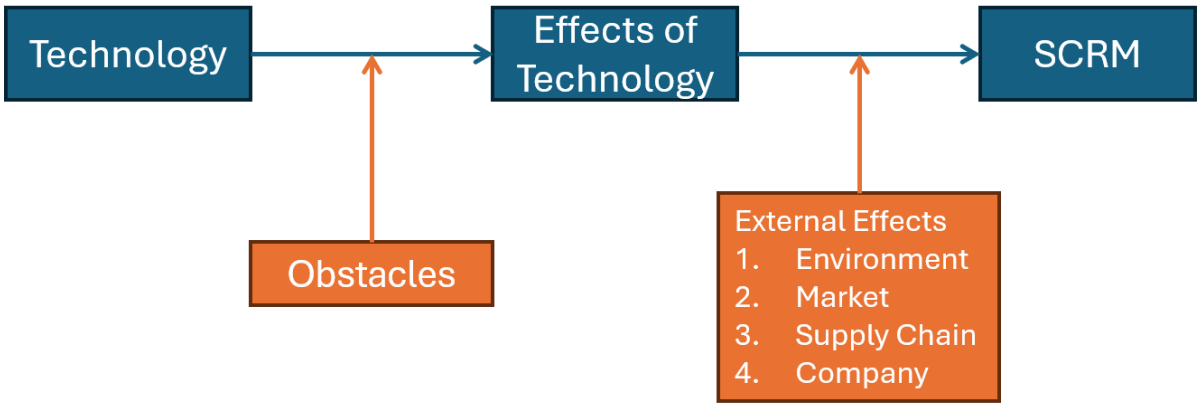

Figure 3 The Final Framework

Component	Key Findings
Technology	- There are many different tools and systems in companies, varying in complexity, purpose, and origin (whether bought or developed inhouse). - No universal solution exists and patchworks of tools are often necessary. - Digital technology is expensive both to procure, integrate, and change, and it competes for resources with other company projects. - Clear objectives must be defined before acquiring new tools to ensure alignment with company strategies and needs. - Human "information bridges" are sometimes required due to lack of integration. - Advanced tools need widespread onboarding to be effective.
Effects of Technology	- Larger amounts of more reliable data enable triangulation of problems. - More data accessibility, availability, and transparency, and better information flow. - Enhanced data management and data quality. - Improved collaboration and communication with stakeholders. - Real-time information allows shorter response times. - Competitive advantages, higher bargaining power, and cost savings in the long run
SCRM	- Digital tools aid in identifying, assessing, and monitoring risks but not directly in mitigation. Continuous monitoring can indirectly assess mitigation strategies. - Real-time tracking and triangulation allow precise risk identification. - Digital systems merge the stages of the SCRM process. - Manual labour remains important for risk identification and mitigation. - Digital tools work best when there is abundant data and slow developments.
Obstacles	- Perceived tool relevance is important for risk managers to use them. - Humans are needed for judgment of results, tool calibration, and decision-making. - Interpersonal relationships and relational capital are important. - The success of digital systems depend on the quality and degree of integrations. - Even small parts can bring an integrated system to a halt if not properly integrated. - Developing, integrating, and changing integrated systems is hard and costly.
External Effects	- Geopolitical events and market dynamics cause demand and supply shocks, affect the availability of materials and services, and makes world trade more uncertain. - Mismatches between processes and digital systems hamper SCRM effectiveness. - Environmental factors (currency, regulations) can offset SCRM improvements. - Supply chain complexity and globalization, as well as company size, structure and degree of centralization, affect risk exposure.

Table 5 Key Findings

5. Discussion

This chapter follows the same structure as the literature chapter to emphasize the connection between prior research and this study. There are two parts to this chapter. The first part concerns risk factors and the SCRM process. This part corresponds to the SCRM component in the framework. The second part addresses technology and its effects, the two other main components. Prerequisites and external effects, the moderators, are treated when relevant.

5.1 SCRM

5.1.1 Interrelated Risks

There was little support or mentioning of interconnected risks in my data despite the ongoing debate in literature about the importance of taking risk networks into account. This was independent of the level of digitalization. Instead, different risk factors were treated in isolation, similar to the findings of Qazi et al. (2018). According to Qazi et al. (2018), a company should target interconnected risks as this provides the highest effect on investment, although interconnected risk factors could appear insignificant compared to other risks. In the data, SCRM efforts were only targeted towards risks with the highest criticality scores in risk maps and matrices, or the ones diverging the most from acceptable values within integrated systems. These observations contradict the clear recommendations of Qazi et al. (2018). In other words, theoretical solutions developed within academia only to a limited extent find their way into industry. My findings support the lack of academic foundations for tool development. Companies know about high-quality research, but the available technology does not sufficiently integrate these findings and insights. It can therefore be concluded that companies want greater implementation of research into the development of tools and systems for SCRM.

5.1.2 The Supply Chain Risk Management Process

According to Gurtu & Johny (2021), cyclicality, demand fluctuations and disasters causes uncertain environments, which in turn lead to supply chain risks. At the same time, Chand et al. (2018) saw internal supply chain complexity as a contributing factor to uncertainty. In other words, both endogenous and exogenous factors contribute to increased uncertainty, which then translates into higher risk levels. In the model developed in the previous chapter, the SCRM

component concerns the risk management process. The output of this process is the aggregated risk level the company faces. With technology and through the effects of technology, the goal is to improve risk identification, analysis, mitigation, and monitoring of endogenous and exogenous risk factors. However, due to increasing risk levels of both endogenous and exogenous risks, the company might experience a rising risk level despite successful adoption of digital technologies in their SCRM. Comparing the aggregated risk level before and after technology implementation could therefore be an erroneous approach to measuring the effect of digital technologies. Instead, if possible, the company should compare the risk level before and after conducting SCRM, then see how these differences change over time.

Risk Identification

Customer and supplier communication and collaboration is one way to identify and resolve risks. However, despite the existence of several frameworks for categorizing risks, my findings indicate these are not used for risk identification in practice. Rather, risks are treated as instances and causes for failure and risk communication could consist of submitting forms on the risks after the disruptive event. In accordance with Lachapelle & Hundozi (2015), distinctions were made between different aggregation levels of SCRM, from individual machines in a factory, to different product markets and regional offices. Aboutorab et al. (2021) argued that risk identification efforts in companies focus too much on internal factors, disregarding the environmental impact on company processes. This research showed that companies indeed do consider exogenous factors like geopolitics and the pandemic because these risks now are more recent in memory. This contrasts the findings of Aboutorab et al. (2021), but supports those Grötsch et al. (2013). Adopting a more structured classification system to risks, in the form of categorization frameworks, could probably improve the identification phase.

Risk identification could also improve in other ways. For example, Ganesh & Kalpana (2022) expressed the need for real-time data within risk identification for early detection and thereby the ability to limit and control the risk already at the initial phases of a disruptive event. This was considered reactive risk identification by Grötsch et al. (2013), and most of the companies used some kind of reactive strategies. In my data, the way information was used enabled risk containment, system alerts, and application of countermeasures in the early phases of a disruption. On the other hand, no technology for proactive risk identification was utilized. Risks were detected when their values exceeded preset boundaries rather than proactively through

what-if models or sensitivity analysis. Ganesh & Kalpana (2022) argued, however, that continuous monitoring leads to proactive behaviours. The level of digitalization in a company heavily affected the ability to use and implement real-time data, as well as continuous monitoring. Small and/or new companies had less incentives to digitalize and implement complex digital technologies because they already considered their supply chains manageable.

Risk Assessment

Risk assessment in the context of technology is closely linked to identification and monitoring and treated in other parts of the thesis. Companies use a mix between qualitative risk assessment with risk matrices, and quantitative risk assessment depending on predetermined thresholds for critical values. There is however no evidence that risks are assessed or measured in financial terms in the way explained by Belgodere et al. (2021). Although the financial impact would add an extra dimension to the cost-benefit analysis, this was not done in any of the companies.

Risk Mitigation

Out of the risk mitigation strategies in the Dohale et al. (2022) taxonomy, multiple sourcing is a popular risk mitigation strategy used by the majority of companies. Redundancy in the supply chain, collaboration with both suppliers and customers, joint planning, and coordination activities are also frequent. Visibility and transparency in the supply chain is also something companies strive for and expect as one of the benefits of adopting digital technologies. Larger companies also utilize risk pooling strategies, similarly to those explained by Sharma & Bhat (2014). These include shifting demand over time by informing customers of later deliver times due to unforeseen SC issues, switching to alternative products when stock levels deplete faster than forecasted, or demand pooling across different markets. Gurtu & Johny (2021) proposed several risk mitigation strategies, among those prevention and rescheduling. They also considered stock an important mitigation strategy, but according to my data there is currently a trend of reducing stock levels in an attempt to adopt a JIT supply chain strategy. This in turn increases the uncertainty and introduces risk. A case can be made about CRMs contributing as data management tools improving managers' understanding of events and supply chain operations, but not enough to disregard safety stock. CRMs cannot replace strategic buffers. Furthermore, companies do not use numerical or economic approaches like insurance, but instead risk treatment plans, similar to those of Belgodere et al. (2021), are common.

Risk Monitoring

Qazi et al. (2018) found that risk managers could be reluctant to change their mindsets and work processes, which corresponds to findings from the interviews. My observations indicate that a change in management and more leadership involvement in SCRM can increase the overall effectiveness of the SCRM, but only as a response to closer leadership involvement. Without regular controls and monitoring of employee and risk manager behaviour, there is a tendency towards stagnation, where ineffective mitigation strategies are continuously reapplied. Continuous monitoring of criticality levels, possible through digital technologies for data collection and analysis, can be used indirectly as an indicator of mitigation strategies effectiveness. If some risks remain critical over time, despite applying risk mitigation strategies, it indicates the applied strategies are ineffective. New strategies must then be developed.

Fully Integrated Systems and Traditional SCRM

In contrast to the clear phases of the traditional risk management process (Aboutorab et al., 2021; DuHadway et al., 2019; El Baz & Ruel, n.d.; Kamakela et al., 2023; Lachapelle & Hundozi, 2015), fully integrated systems blur the distinctions between the phases. Thorough automatization, the company achieves constant monitoring of information. Different tools decode and analyse the information and identify changes. If the values lie outside of the threshold values, the risk managers are alerted and, depending on the tool, also provided recommendations on how to mitigate the risk. In other words, monitoring is closely linked with both identification and analysis, but only partly or indirectly to mitigation. According to these findings, the focus should be on risk mitigation in contrast with the views of Fischer-Preßler et al. (2020). These findings are more in line with the view of Grötsch et al. (2013), that detection and control systems must be closely integrated with strategies, and that detection and control are one and the same. Ganesh & Kalpana (2022) had similar views on how constant monitoring of social media and newspapers could identify risks at an early stage, enabling the company to respond before the risks become highly critical and propagate in the company or supply chain.

5.2 The Role and Impact of Technology in SCRM

5.2.1 Sentiment and Attitudes Towards Digitalization

Consistent with prior research, technology was considered something positive in my data and companies want more of it. Digitalization projects is a frequently visited topic. Either companies have just been through such projects, were currently undertaking one, or plan on starting new projects in the near future. The experienced and expected benefits are too numerous to list, but include real-time information, traceability of input factors, automated customer and supplier communication, higher data quality and better data management, improved data analysis, information sharing and supply chain collaboration. With technology, information is easier obtained, leading to higher-quality decision-making. Visibility and a better understanding of emerging issues, more accurate forecasting, and scheduling were also mentioned.

5.2.2 SCRM Technologies: From Enterprise Systems to Machine Learning

Large enterprise systems (ES) like SAP are in all kinds of companies and are in most cases integrated with the SCRM tools and systems. In this way, information sharing is possible across company units. Data from different information points can also be combined and compared to triangulate problems or to detect discrepancies and opportunistic behaviour at any part of the supply chain. Enterprise systems therefore help identify, assess, and mitigate risks in complex and uncertain environments, in line with the findings of Sambhara et al. (2016). Complementary enterprise systems (CES) are use in most companies, like CRMs and systems particularly developed for SCRM purposes. Those too support Sambhara et al. (2016).

Moreover, Sambhara et al. (2016) found a larger need to digitalize cross-functional processes and complementary enterprise systems in complex environments. My data supports this finding, as large companies with complex supply chains and company structures perceive digitalizing of even smaller and more secondary activities as important to improve the flow of goods. Due to large transaction volumes, developing and implementing CESs is beneficial. Chand et al. (2018) reported similar findings.

Similar to the findings of Sambhara et al. (2016), company systems can provide real-time updates and an overview of several key aspects of the supply chain, like demand or market changes. The need to manage the uncertainty and equivocality emerging from the large amounts of data, caused by enhanced data collection, can therefore be considered another

driving factor behind the development of advanced systems, in line with DuHadway et al. (2019) and El Baz & Ruel (n.d.). The fully integrated systems developed inhouse by companies resemble ERM systems where risk detection and control are closely integrated (Grötsch et al., 2013; Villanueva et al., 2022). However, company and mitigation strategies are only integrated to a limited extent in the systems developed inhouse, and if so, only as recommendations. The systems do not themselves execute on the mitigation strategies.

Machine learning and real-time data collection are used by some companies, but far from all. Combined with increased data collection higher data quality, more powerful and accurate forecasts can be made (Balakrishnan & Ramanathan, 2021; Nikolopoulos et al., 2021). Advanced data analysis tools, like machine learning, contributes to predicting dynamic patterns in the market and environment. This supports the findings of Nayal et al. (2022). Digital systems and technology furthermore can assist in contract management, freight booking, planning, contactless delivery processes, in building RPAs as part of the digital workforce, and with automated product handling and warehouse management. These findings corresponds with those made by Balakrishnan & Ramanathan (2021).

Digital tools and systems can significantly improve the risk managers' abilities to understand events and the scope of events, but also direct the manager's attention towards the more pressing and critical issues, in line with the findings of Fortner (2021). Improved SCRM, as observed by Song et al. (2024), is facilitated in companies through information sharing with upstream and downstream partners, enhanced data collection, demand forecasting, clear channels for information flow, real-time information, transport tracking, and abnormality warnings. Consistent with the findings of Fortner (2021), some companies implement data systems that capture data about both upstream and downstream supply chain partners, enabling quicker and more efficient problem solving. Through data visualization and easy access to more relevant data on supplier and customer relations, timely resolution of efficiency problems is possible, drastically decreasing information risks. This aligns with the work of Balakrishnan & Ramanathan (2021). However, problems can arise when not all supply chain partners have access to the platform or data. The company controlling the platform gains a competitive advantage as the gatekeeper of information, potentially at the expense of overall supply chain performance. Fortner (2021) argued that all authorized parties should have access, but this is apparently not always the case. The platform owner might also face challenges if supply chain partners do not provide sufficient information about their plans, new contracts with their suppliers or customers, sales campaigns, or other supply chain related issues. This can lead to

coordination problems. By granting access to all supply chain partners, they could independently extract important information, update their forecasts and models, and share their own data. Solutions resembling to those proposed by Fortner (2021) and Balakrishnan & Ramanathan (2021), but they can be improved and made more inclusive.

5.2.3 Standardization and Customization

Contrary to the claims of Zimon & Madzik (2020), standardized tools and systems are perceived negatively by all companies who have tried them. This is because standardized solutions not sufficiently satisfy company objectives and needs. Either they do not align with the methodology, or they lack important functionalities. There seems to be three solutions to the problem of standardized tools: (1) customization, (2) in-house development of new solutions, and (3) manual labour, which was observed among smaller companies. For businesses with lower transaction volumes and simpler supply chains, manual labour suffices to manage the supply chain. Doetzer & Pflaum (2021) noted that companies can achieve comparable results from conventional and existing infrastructure as they would with technology.

Villanueva et al. (2022) turned the problem on its head and argued that companies are too rigid to adapt, rather than the tools being insufficient. They put the tool in the centre and regarded the company as a context that must change. Some companies try this approach, but eventually some degree of customization is inevitable for systems to work properly. In large companies view the company as the core, and digital tools as something that must fit or assist the processes and structures within the company. Digital technologies are means, not ends. There is no reason to digitalize a process just because some technology exists that could do the job.

5.2.4 Defining Clear Objectives for Effective Technology Implementation

Similar to the findings Kamakela et al. (2023), risk mitigation overshadows the development and implementation of comprehensive risk management strategies. Digital technologies are in some cases not sufficiently implemented. For tools and systems to be used, they must be perceived as relevant to the work and helpful to the employees using them. Otherwise, the technology is likely disregarded. Forcing employees to use technology they view as irrelevant only negatively affects their attitude towards it. My findings indicate that it leads to opportunistic behaviour where the tool is disregarded. Instead of improving SCRM, the tools

were “just another thing to be done” and stole time and resources from the SCRM activities. This underlines of the importance of risk detection and control systems being closely integrated with the strategies and counteractive actions, discussed by Grötsch et al. (2013). Digital tools and systems must align with company strategies and SCRM objectives to obtain optimal results. The data collected in this study can therefore be interpreted in the sense that companies not always implement technology sufficiently, aligning with the findings of Kamakela et al. (2023). There were several reasons for this, but the most important cause was that existing tools not satisfied company needs and or solved the issues.

When building complex and fully integrated ERMs, the objectives of each additional tool must be clearly defined in advance to avoid tool propagation in the company, to align with company strategy and objectives of SCRM, and to reduce the number, and thereby cost, of system integrations. Villanueva et al. (2022) similarly pointed out that the system development depends on the company context. One reason it is important to develop and implement tools and systems with a clear purpose, contextual understanding, and defined objectives is to reduce technology and process uncertainty (Kessler et al., 2024). Without sufficient clarification on objectives and needs, acquisition processes and system development processes tended to move off track. Sometimes though, the tools do not fit directly into the system or fully meet all company needs, making a patchwork of different tools necessary.

5.2.5 The Role of Manual Work in an Increasingly Digital Supply Chain

Consistent with Doetzer & Pflaum (2021), digital tools and systems can significantly assist risk managers, but several areas of SCRM are still manually executed. They also found that the same flexibility achieved with technology is possible using existing infrastructure in companies, making it impossible to see any immediate effects or additional benefits of the technology. For some companies, manual labour is actually preferred over digital solutions due to high costs of investment, development, implementation, and integration of digital solutions. The destruction of relational capital is also a deterring factor, especially when close relations with supply chain partners provide competitive advantages compared with competitors.

There are different opinions on the role technology will play in the coming years. On the one hand, Doetzer & Pflaum (2021) argued that technology can replace risk managers, meaning SCRM activities are fully conducted by digital technologies. On the other hand, Gurtu & Johny (2021) emphasized that strong relationships with supply chain actors contribute to securing

demand. Considering that digital systems may remove the human touch points between different actors, the gains in efficiency must be compared to the possible reduction of relational capital, in addition to a cost-benefit analysis for the tool integration and implementation.

Interestingly, my findings also suggest that digital tools provide wrong or potentially harmful recommendations due to a lack of contextual understanding typically possessed by humans. For example, increasing sales numbers may might necessarily mean a new trend is emerging. Risk managers are therefore needed to control check recommendations before they are implemented, to ensure the soundness of conclusions. Replacing risk managers could in fact harm business operations because erroneous mitigation strategies would be implemented to counteract issues that only exist on paper and not in reality. Digital solutions can be helpful, but currently fall short on the contextual and qualitative understanding. Risk managers are still needed in SCRM, but digital tools may increase their productivity, in line with the findings of Nayal et al. (2022).

There is also the issue of configuring digital tools to make them operational, including specifying risk factors and defining acceptable threshold values. Digital also struggle to identify new kinds of risk factors and risks that develop rapidly. Before companies can fully replace risk managers, there is a need for more intelligent systems able to understand and consider the business context. That said, fully integrated systems have, to a large extent, already taken over risk identification of common risk factors, assessment after acceptable threshold values have been specified and configurated, and the continuous monitoring of developments in criticality values over time. Additionally, digital technology can provide deep insights and detect more complex patterns in data than can humans, given data abundancy. Able to understand more of the intricate relationships between different components of the supply chain, digital technologies may outperform risk managers in certain areas of SCRM.

Consequently, digitalization might cause anxiety among workers and instil fear of job loss. Saldanha et al. (2015) noted similar concerns regarding job security. Kessler et al. (2024), however, argued that human resources would be reallocated to more tactical and strategical long-term tasks. Both scenarios were observed in my data. In both cases, the companies made an effort to communicate and clarify their intended actions in advance to reduce uncertainty and, consequently, employee anxiety. Providing clear information is important, as knowing what to expect allows workers to prepare for the inevitable. Nevertheless, considering the centrality of risk managers, especially in identifying rapidly developing risks, the need of risk managers will most likely remain for several years to come. This holds especially true in smaller companies with lower levels of digitalization, simple supply chains, and limited budgets.

5.2.6 Data Access and Availability, A Double-Edged Sword in Supply Chains

Along the lines of Nayal et al. (2022), my findings indicate that collecting data from several points and partners in the supply chain provides a clearer understanding of when and where in the issues arise. Early identification of these issues enables the company to work collaboratively with transportation providers, suppliers, and customers to develop solutions. Methods for data collection, such as time stamps and EDIs, reflect observations by Urciuoli & Hintsa (2018). Sharing performance metrics, demand forecasts, production and delivery schedules, as well as inventory and sales data, enhances SCRM effectiveness and efficiency. Nonetheless, the accessibility and availability of information in the supply chain remain a double-edged sword.

On the one hand, my findings support the argument by Nayal et al. (2022) that digital tools improve the accessibility and availability of information within companies, breaking down silos and reducing duplication of work. The structured way in which digital tools keep track of information provides easier access to data, deeper insights derived from the data, and the ability to track what input factors are related with what batches, transactions between company units and supply chain partners, while also improving regulatory compliance. On the other hand, greater accessibility and availability of data can also be harmful, as more people gain access to sensitive information, increasing the risk of leaking sensitive information. If exploited, sensitive information could harm a company's competitiveness. Although access to information can be regulated, technical glitches still occur. In other words, increased accessibility and availability of information is not always positive.

5.2.7 From Critical Tasks to Fully Integrated Systems: A Digital Evolution

It is a common perception that digital technologies can benefit SCRM and improve business processes. However, the extent to which tools can be used, and the benefits to be gained from a specific technology, depend on how central the tasks are to the company's operations. Some tasks are critical, encompassing large sections of the company and exhibiting significant complexity in both scale and scope. Others are smaller, more peripheral, and serve as supportive functions to the central tasks. The normative claims of Zimon & Madzik (2020) – that companies with limited budgets should implement standardized management systems – should therefore be contextualized based on the criticality and centrality of the tasks the technology is intended to digitalize. It is important to note that perceptions of what constitutes critical areas for improvement may vary across the supply chain, as highlighted by Shenoi et al. (2018). In

most cases, implementing digital technology for critical tasks, such as those in the production line, provides greater value than digitalizing more peripheral tasks.

However, in fully integrated systems, peripheral tasks should not be overlooked, as sum of all integrated tools contributes to a more holistic view on company processes, production, delivery and stock levels, supply chain partners, and the external environment. Extensive data collection, combined with big data analytics and AI, enables the identification of complex patterns in data, provides deeper insights into particular issues, facilitates triangulation of issues, enhances monitoring, and ultimately improves risk identification and assessment.

There appears to be a spectrum on which companies can be placed based on their level of digitalization and technology adoption. At one end of the spectrum are companies just beginning their digitalization journey, focusing primarily on digitizing central activities, such as basic information management. As the number of digital tools and digitized tasks increases, so do the opportunities for leveraging additional technologies. A gradual digitization of key tasks, one after the other, can eventually lead to a full digital transformation. This process builds competencies and capabilities over time, reflecting a digital evolution rather than a sudden digital revolution. Of course, both approaches may coexist, but this perspective highlights the progression of digital adoption. It also provides insights into the service gap in risk management between manufacturers and suppliers (Shenoi et al., 2018), and the mismatch between risk levels and SCRM efforts (Kamakela et al., 2023). A company might not yet have reached the stage where they see the benefits of digitalizing activities enhancing their supply chain.

Villanueva et al. (2022) argued that the size and age of the company do not matter for development of ERM. My findings, however, suggest the opposite. Larger companies were also those with most digital solutions and fully integrated systems, while smaller companies lacked advanced digital tools. No significant difference was observed regarding the age of companies,

5.2.8 Large Companies Drive Supply Chain Digitalization

According to Nayal et al. (2022) technology can provide competitive advantages. My data supports this claim. Improved data quality, collection, and analysis lead to deeper insights, enabling better decision-making. Deeper insights are particularly valuable when negotiating with suppliers and customers. At the same time, earlier identification of risk factors facilitates more robust supply chain collaboration. When large companies digitalize, they often compel their suppliers to follow suit to ensure integration with their systems. This, in turn, standardizes data among the supply chain partners, making it easier for digital tools to analyse.

There is also another way of looking at the concept of technology propagation within the supply chain. From a more altruistic perspective, larger and more specialized companies should be at the forefront of tool development, as digitalization would provide large gains due to their large transaction volumes and more complex company structures. At the same time, enhanced data management across company units and regional offices could increase the collective bargaining power of the company, leading to competitive advantages and stronger bottom lines.

In either case, large companies become drivers of digitalization within both their supply chains and industries. Given different approaches to obtaining the same results, managers should consider their influence and choose the strategy that best suits their environment and context.

5.2.9 Investment Costs and System Failures Discourage Digitalization

So far, we have explored several benefits and upsides of digital technologies. These are numerous, but why don't companies adopt more technology then? The main factor deterring companies from digital transformation is cost, as noted by Kamakela et al. (2023). Additionally, it is often hard to see the immediate benefits of supply digitalization, as highlighted by Sreedevi & Saranga (2017). My finding further support Kessler et al. (2024), who found that technology implementation is more problematic in small and medium-sized enterprises (SMEs) due to the high investment costs relative to earnings, assets, and potential gains. A similar relationship was observed in this study between digitalization of secondary activities and company size.

In smaller companies, transaction volumes and potential revenue gains are often insufficient to justify the acquisition of digital technology. At the same time, the investment constitutes a larger percentage of their financial assets compared to larger companies, making the investment financially riskier. Additionally, with limited budgets, the opportunity cost of other projects

becomes an important consideration. High investment costs, low returns of investment, considerable opportunity costs, and benefits that materialize only in the long term can be discouraging. Therefore, companies tend to focus on addressing only the most pressing issues, even when a project eventually could prove profitable. As Qazi et al. (2018) noted, the cost-benefit analysis and return on investment can act as deterring factors, independent of company size. Other barriers include the destruction of relational capital, resource constraints, and trade-offs with competing projects. No support was found for the assertive claim by Ganesh & Kalpana (2022) that data-driven approaches are necessities, and it does therefore does not hold.

Paradoxically, while digitalization is intended to reduce costs, high investment costs often discourage digitalization efforts, preventing companies from digitalizing processes and tasks. According to my findings, many companies have digitalization plans but postpone investments if other priorities are considered more important. Even larger companies delay digitalization projects due to resource and time constraints. In other words, digitalization plans are subject to trade-offs with other initiatives and are influenced by the risk appetite of decision-makers, consistent with the findings of Qazi et al. (2018).

Another point made by Nayal et al. (2022) is that technology reduces hitches and breakdowns of machines, improves quality, and ensures product availability. However, reaching this point requires time and effort. Moreover, even after implementation, technological glitches and coding errors can still occur. Inn fully integrated systems, even minor errors at a single workstation can disrupt the entire production line. Similar to the relationship between supply chain complexity and length, the production and system complexity within the company can also influence the need and effectiveness of digital technology.

6. Conclusion

This thesis has examined the question: *How can the use of digital technologies improve supply chain risk management?* There is no single or simple answer to this question. It depends on the risks the company is facing, the technology currently present in the company, what processes and activities are conducted, and how central they are to operations, and lastly, characteristics about both the company, supply chain, market, and business environment. This thesis has shed light on some important commonalities and, at large, it can be concluded that digital technologies indeed improve SCRM.

In terms of digital SCRM, system integration play a central role because most of the steps of the traditional risk management process now can be conducted by the tools and systems. This frees up resources for other areas, saving risk managers time for the most critical issues. With digital technologies, risk identification, analysis, and monitoring all merge and become one simultaneous analysis. Constant monitoring of the market enables early risk identification whenever risk values exceed acceptable thresholds. Risk mitigation is, in contrast, largely manual. However, digital tools could be used to indirectly assess the effectiveness of risk mitigation strategies by monitoring developments in risk criticality over time. When the same countermeasures have been applied several times without any significant changes, the countermeasures must be adjusted or replaced.

There are several different tools available. Each company have their own tools and systems, some of which are self-developed. These tools can be combined to build advanced systems. Digital technologies provide a myriad of different benefits that can improve SCRM. These include more collected data, and thereby triangulation of issues, real-time system alerts, high-quality data, as well as improved data analysis and detection of more complex patterns. Improved data management, accessibility, and availability, both within the company and the supply chain, leads to better coordination of SCRM efforts among supply chain partners, thereby better problem-solving. By combining several of these benefits, deeper, better, and more reliable real-time insights on a larger part of the chain and environment can be derived, enabling more efficient and targeted SCRM, both proactive and reactive. Proactive SCRM is possible because the company better understands weak points in their supply chain, as well as the effect of environmental factors. Reactive SCRM improves through early detection of disruptive events, and they can therefore be contained and resolved before causing any significant damage or propagating to larger or more critical parts of the chain.

As a structured way of answering the research question, but also to provide a starting point for further research, a framework was developed which shows the effects of technology on SCRM. Between technology and the SCRM process, we find the effects, or benefits, of technology. However, the effects of technology can be interrupted by improper implementation, insufficient employee training, misalignment with company strategy, or weaknesses inherit to the technology itself. Similarly, endogenous and exogenous factors reduce the effectiveness of SCRM process to lower the aggregated risk level facing the company. Therefore, gains in efficiency and effectiveness derived from technology, may be hard to identify or measure. We also saw that manual labour still plays a central role within all stages of SCRM, from identification of rapidly developing risks and configurating tools to evaluation of automated risk analyses and mitigation strategies. Nevertheless, there is no doubt digital technologies has the potential to improve SCRM and provide security in a time of change worldwide.

6.1 Theoretical and Managerial Contributions

The focus of this thesis has been the use of digital tools and systems within SCRM, an underdeveloped area of the SCRM literature. Therefore, this thesis marks a starting point for a new branch within the SCRM literature, but also provides a structured approach to understanding digitalization projects related to SCRM. At the same time, this thesis presented a holistic understanding of how all the stages of the SCRM process interact, and how they are influenced by digital technologies and environmental factors. Doing this, we saw that technology, through intricate systems of connected tools, blur the distinctions between the steps of traditional SCRM, merging them into one coherent and simultaneous activity. On the one hand, this improves the quality, speed, and efficiency of SCRM. On the other hand, it can be harder to assign tasks to risk managers or lead to changes in how companies manage risks.

Although there exist several different kinds of digital technologies, there are currently no solution to solve all SCRM problems. Each company must therefore be aware of their business environments, clearly define objectives and needs before adopting new technologies, and develop SCRM strategies, aligned with company strategies, for how the technology should be implemented and utilized to achieve it. A patchwork of overlapping tools and systems are in many cases necessary to address the sum of SCRM issues, and companies considering adopting new technology must be aware they need to integrate the new technology within the existing system and digital infrastructure. Given the power of large companies to influence digitalization

in supply chains, these should also take the overall supply chain performance into account when designing plans and strategies for SCRM digitalization. Employees and risk managers are important stakeholders influenced by digitalization processes and must not be forgotten. From the beginning of a project until its completion, it should be clearly communicated how the changes will affect them and their jobs independent of the outcome. This will reduce their anxiety and enable them to plan and prepare for potentially negative and harmful outcomes.

6.2 Limitations and Avenues for Future Research

Some limitations of this study have already been addressed, such as the data collection not reaching data-saturation – the goal of qualitative research. Consequently, it may be that not all relevant data was collected. Other limitations include the method of retrieving samples from the target population, which might be biases and lead to incorrect conclusions (Saunders et al., 2016, p. 275). There were only six companies in the sample, all of which were either Norwegian or Swedish. This also raises concerns regarding the representativeness of the sample and the potential for participation bias. As explained by Saunders et al. (2016, p. 397-398), reliability and dependability issues are inherit in qualitative studies. It is hard to replicate the findings because they reflect the time and context in which they were obtained. Neither can statistical generalisations be made about an entire population based on a small non-probability sample (Saunders et al., 2016, p. 400). Additionally, due to an inexperienced researcher, there is a high likelihood of interviewer bias influencing the answers given, as well as the interpretation and decoding of data, despite the efforts undertaken to prevent and reduce the impact of these biases.

Moreover, technical issues affected data collection and analysis. First of all, the sound recordings were of poor quality due to limitations in the equipment and because the interviews were all internet-mediated. During each interview, there were moments where it was impossible to hear or understand what the informant was saying. The cause behind these technical glitches was unfortunately never identified but lasted for several seconds each time. The information provided during these periods was unfortunately lost. Second, all the interviews were internet-mediated, drastically reducing the number of observable non-verbal cues. This too could have had an impact on the interpretation and coding of the data.

Considering the framework, there are important elements that are hard to fit into any one category, for example the role of manual work, because it is important and affects several elements. In some cases, elements like the effects of technology and the improvements of

SCRM, are hard to distinguish from each other. Additionally, some of the same factors included in obstacles could also fit into one or more of the external effects affecting SCRM. Future research could map out and more precisely define each of the components.

Several research avenues remain, but this thesis hopefully provides a starting point, and inspiration, for future research. To name a few, quantitative studies should be conducted on what effects of technology are the most important, common, easily obtained, and have the most significant effects on SCRM. Quantitative studies should also be conducted to test the relationships between the elements in the framework, especially since these already take the form of mediation and moderation effects. Likewise, deductive studies could test the reliability of the framework within different contexts and to what degree it is applicable within other industries. Furthermore, this is a holistic approach to technology within the context of SCRM and further research could target each element of the framework more in-depth.

On the contextual side, a natural next step would be to examine how well adopted technology aligns with company objectives, the initial digitalization plan, and company strategies. Also, to what extent do companies correctly assess the potential of different digital technologies for their companies, and what factors may distort or improve these assessments? Diachronic and/or longitudinal studies tracking company development over time, based on an initial level of digitalization, would also be interesting. What, if any, are the long-term effects of digitalization and digital SCRM technology? Do companies change as a result of technology adoption?

It must also be mentioned that this study was conducted in the aftermaths of covid-19, in a time of increasing geopolitical tension and social unrest. Some of the responses were clearly influenced by these changes. At the same time, new technologies are constantly developed, directly affecting the available solutions on the market. Due to constant changes and continuous improvements, it would be interesting to conduct the same study in some years to see how companies reacted to these trends and what digitalization strategies turned out the most beneficial in the long run. Hopefully, this thesis will spur further research in the field, contribute to the development and adoption of more integrated and efficient SCRM systems, and thereby lead to safer supply chains and a more connected world.

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Appendix 1 – List of Search Terms

Effects of Technology on SC Risk Management	SC Risk Management
Decision-support systems	Supply Chain Risk Management (SCRM)
Supply Chain Risk Management (SCRM)	Importance-performance analysis (IPA)
Cyber supply chain risk management (CSCRM).	Risk Mitigation Strategies (RMS)
Digitalized information-sharing (DIS)	Strategic action grid
Supply chain resilience	Risk monitoring
digital technology and analytics for holistic supply chain risk management	Risk avoidance (RA)
internal assessment	Risk sharing
external assessment	Demand uncertainty
risk mitigation strategies	Disruption risks
Flexibility approach – multiple sourcing	Operational risk
Redundant approach – strategic/safety stock	Supply chain flexibility
Reactive and proactive risk assessment	Delivery/logistics flexibility
Risk monitoring	Risk mitigation strategy matrix (RMSM)
Supply Chain data collection	Resilience
Risk management analysis	Emerging markets
Virtual dual sourcing (VDS)	Vulnerability Mitigation Strategy (VMS)
Ripple effect	
Supplier disruption	
Digital empowerment theory	
Information flow integration	
Physical flow integration	
Financial flow integration	
Supply chain capabilities	
Supply chain structure	
Dynamic capability theory	
Supply chain disruption risks (SCDRs)	
Supply chain dynamic capability (SCDC)	
Industry 4.0/5.0	
Supply chain digital transformation	

Appendix 2 – Interview Guide

Ethics and Consent (5 min)

Inform the participant about their rights, the purpose of the interview, how data will be stored and treated:

- Participation is voluntary and you can withdraw whenever you want without giving a reason.
- All information will be anonymised in the thesis.
- There will be no negative consequences for you if you choose not to participate or to later withdraw.
- The data will only be accessible to me as a researcher, and my two supervisors.
- Your name will not be visible in the material or final thesis. Your company name will be mentioned, but not linked to your answers.
- The interview will be transcribed and decoded as soon as possible.
- The recordings will be deleted after the project is done.

Opening Question (5 min)

1. Can you introduce yourself, your company and describe your upstream and downstream supply chain?

Topic 1: SCRM (10 min)

2. What does your SCRM (supply chain risk management) process look like?
    a. How is it organized and executed in your company?
    b. Where is it positioned in the company?
    c. Who is responsible and/or involved in your SCRM?

3. What do you consider the most important supply chain risk factors?
    a. How do you distinguish risks and how do you manage different categories of risk?

Topic 2: Current tools/systems (15 min)

4. Can you describe how your organization uses digital tools and systems for supply chain risk management (SCRM)?
    a. What parts of the SCRM?
    b. What kind of tools/systems? Examples please
    c. Do you use the same tools/systems for all kinds of risk?
    d. Why these tools and systems?
    e. What criteria do you use to pick tools/systems?
    f. What effects/differences have you experienced, either positive or negative, from using tools/systems? Provide examples please.
    g. To what extent do the tools/systems satisfy performance expectations? Worse, better or as expected? Provide examples please.
    h. Are there any negative consequences of the tools/systems? Provide examples please.

5. Can you provide examples of any challenges you faced during the implementation of the digital tools/systems?
    a. How did you overcome these challenges?

Topic 3: Views on SCRM tools/systems (15 min)

6. At which parts of SCRM do you consider digital tools/systems the most beneficial?
    a. How?
    b. Why?

7. In general, have you experienced, or do you see, any negative effects or problems with using digital tools/systems? Provide examples please.
    a. How are/can these problems be addressed?

8. What is your company's future views on tools/systems and why?
    a. Keep it as it is

b. Use more
c. Use less

9. In general, what do you consider necessary to succeed with implementation of SCRM tools/systems?

Concluding Question (5 min)

10. Is there anything you would like to add?

11. Do you have any questions?

Total length: 55 min

Appendix 3 – Email Used to Contact Companies

Translated from Norwegian to English by ChatGPT.

Hello!

My name is E. Samuel C. Braaten, and I am a double degree student at NHH in Bergen and UCL/LSM in Belgium, writing my master's thesis on how digital tools and systems can strengthen risk management in supply chains (supply chain risk management/SCRM). [*Company name*] is interesting due to [*customized message/reason*]. My question is whether you have the opportunity to have a conversation in the next 2-3 weeks, preferably as soon as possible.

The questions will revolve around SCRM at your company and what kind of digital systems and tools you use for risk management, how you use them, and why you have chosen these tools/systems, the positive and negative effects of using them, challenges, etc. If desired, I can also send over the questions in advance, but with the understanding that they may change depending on how the thesis develops.

To elaborate on the thesis, it is qualitative, exploratory, inductive, and utilizes semi-structured interviews as a method. The literature on supply chains uses a tripartite division of upstream, own production, and downstream since various risk factors tend to influence each other. The value chain, both upstream and downstream, would be interesting, but any information would help. There is almost no research in the area, so the study is exploratory regarding the drivers behind and effects of using digital tools/systems in SCRM, both positive and negative. The goal is to build a kind of framework that can explain relationships and provide a basis for further research in the area.

An interview with you on these topics would greatly assist me with my master's thesis.

Best regards,

E. Samuel C. Braaten

Appendix 4 – Codes and Themes

Technology	Obstacles	Effects of Technology	External Effects	SCRM
Automation/robots	Attitudes	Accessibility	changes environment	Decision making (could be effects)
Criteria for system	Drawback	Accessibility&availability	changes risk environment	Demand risk
Criteria system	Focus	Accessibility/availability	Company Info	Disruption
Development process	Functionality (could be effects)	Adaptability	company information	Frequency updates (quality control)
Digital system	Human error	Benefit	Company structure	Frequency updates (risk factors; information)
Digital system/tool	Industry comparison	Benefits	Downstream supply chain	Holistic
Digital systems/tools	Insufficient	Comparative advantage	Downstream supply chain	Prioritization in risk assessment
Digital tool	Insufficient system	Competitive advantage	Environmental changes	Proactive
Digital tool (	Insufficient system/drawback system	Complexity	Market	Process evaluation
Excel	Insufficient tool	Cost reduction	product characteristics	Production/process control
Frequency updates	Insufficient tools	Customer communication	Product/service criteria	Quality checks
Information updates	Investment	Data aggregation	seasonality demand	Quality criteria
Inhouse development	Leadership involvement	Data analysis	Supply chain structure	Reactive
Machine learning	Management involvement	Data collection	upstream supply chain	Risk acceptance
Need for system/tool	Open to use and apply tools/systems	Data management		Risk analysis
Need tool/systems (effects of technology?)	Relational capital	Data quality		Risk assessment
Need tools/system	Relevance	Data source		Risk communication
Need tools/systems	Resource constraint	Data sources		Risk factor
Standardization	Resources	Data visualization		Risk factors
Switching cost (could be moderator t/e)	Responsibility	Decision making (could be SCRM)		Risk identification
System criteria	Responsible	Demand forecasts		Risk impact
System development	Responsible person	Efficiency		Risk management
System update	Simplification (could be effects)	Efficiency/effectiveness		Risk management process
System updates	Switching cost (could be technology)	Flexibility/adaptability		Risk mitigation
Technology (robots)	System integration	Focus		Risk monitoring
Tool development	Technical problems	Forecast		Risk relationships/network
	Training	Forecasting		Risk relationships/networks
	Unhelpful tool	Frequency updates (measurements and data from customers)		Risk reporting
		Functionality		Risk reports
		Information flow		SCRM process
		Information points		Supplier relations
		Information sharing		Supply risk
		Information sharing/flow		Supply risk, logistic risk
		Internal communication		Vertical integration
		Prioritization		
		SC collaboration		
		Scenario planning		
		Simplification (could be moderator t/e)		
		Simulation		
		Supplier collaboration		
		Supplier communication		
		Supplier relations		
		System alert		
		Tracking		
		Transparency		
		Trend		
		Visualization		
		Warning signal		
26	28	48	14	34

Appendix 5 – Extracts from Email Correspondence with Sikt, NHH, and LSM

The correspondences with Sikt and NHH were originally in Norwegian, but here translated using ChatGPT for the conveniency of this thesis.

Response from Sikt 31.07.2024

Hi,

We don’t have access to share the notification form, but you can do this yourself at minforskning.sikt.no by going into the project and selecting “Share.”

We also note that you’ve stated in the information sheet that NHH and UCL are joint data controllers. Have you confirmed with NHH that this is accurate, and has an agreement been made regarding joint data responsibility? If so, UCL should also be listed under "Data Controller" in the notification form.

Please note that we do not have an agreement with UCL, so the information sheet should not state that we have assessed anything on their behalf. UCL must ensure that its processing of personal data complies with European and Belgian data protection laws.

If UCL is not actually a joint data controller, the information sheets will need to be revised to clarify that NHH alone is responsible. In that case, personal data must be processed solely within NHH’s systems or according to NHH’s guidelines, and NHH must independently determine the purposes and methods.

You can read more about joint data responsibility on Datatilsynet's website: datatilsynet.no/rettigheter-og-plikter/virksomhetenes-plikter/behandlingsansvarlig-og-databehandler/felles-behandlingsansvar

We recommend that you contact the research administration at NHH if you are uncertain about data processing responsibilities.

Email to LSM 20.08.2024

Hello!

Are there any ethical concerns or do I need any approvals of my research project at LSM before conducting interviews with companies? Finally, I have gotten hold on some informants. Before the interview I send them this together with the interview questions. At the beginning of the interview, I also read it to them.

Ethics and Consent (5 min)

Inform the participant about their rights, the purpose of the interview, how data will be stored and treated:

- Participation is voluntary and you can withdraw whenever you want without giving a reason.
- All information will be anonymised in the thesis.
- There will be no negative consequences for you if you choose not to participate or to later withdraw.
- The data will only be accessible to me as a researcher, and my two supervisors.
- Your name will not be visible in the material or final thesis. Your company name will be mentioned, but not linked to your answers.
- The interview will be transcribed and decoded as soon as possible.
- The recordings will be deleted after the project is done.

Best regards,

Samuel Braaten

Response from LSM 21.08.2024

Dear Samuel,

There are no ethical concerns involved, so you can go ahead.

Best regards.

Response from NHH 22.08.2024

Hi Erlend,

The question regarding the privacy assessment was forwarded to me by [person] at NHH. I am the [title] and can assist with questions about data protection regulations.

I understand that you've been in contact with Sikt regarding your project, and there were questions raised about joint data processing responsibility.

Feel free to reach out to me, and I can help clarify. I can also assist in evaluating whether your project requires consultation with me. The duty to consult with the Data Protection Officer is the reason we use services from Sikt, and most student and research projects do not fall into the category requiring consultation.

I'm available between 12 – 2 PM today, or tomorrow morning. Alternatively, just let me know what works best for you; I'm quite flexible.

Best regards,

[Person]

Response from NHH 09.10.2024

Hi Erlend,

You don't need to worry. You are correct in noting that it's not Sikt that approves your project; the institutions do that. Essentially, you probably wouldn't have needed to consult Sikt, and having the project listed as "unresolved" likely isn't significant.

When it comes to data processing responsibility under the data protection regulations, it pertains to the processing of personal data, not the responsibility for your project itself. According to the regulations, when two or more data controllers (institutions) jointly decide the purpose of personal data processing and the means (such as how the data will be processed, including information security), they are considered joint data controllers. In such cases, responsibility must be clarified and allocated between the parties through an "arrangement" (as specified by

the law), and participants (data subjects) must be made aware of these responsibilities. There's no need for a separate agreement on joint data responsibility if it has already been agreed upon between institutions regarding how the project will be conducted. For participants, it is sufficient that the information sheet specifies that the project is carried out as a joint degree.

Furthermore, all matters related to research ethics, such as providing information to participants and obtaining consent, are not within Sikt's advisory scope. This responsibility falls under the institutions' remit for research ethics. Thus, you are not dependent on any type of approval from Sikt. However, if you still prefer not to have your project listed as "unresolved," you can specify both institutions and inform Sikt that responsibility has already been clarified through an existing agreement between the parties for your degree.

Feel free to reach out if you have any questions.

Best regards,

[Person]

Response from Sikt 09.10.2024

Hello, and thank you for your response.

It sounds like the project does not require our assessment. If NHH has a role in the processing of personal data, we understand NHH's feedback to mean that our evaluation is not necessary, as the duty to consult does not apply. The consultation obligation only applies to projects that process sensitive personal data related to health, religion, etc. (special categories).

We will therefore register the notification form as withdrawn. However, if it turns out that the project does require our assessment after all, you can reopen it at any time by resubmitting the notification form.

Hope this clarifies things.