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POLYTECHNIQUE MONTRÉAL

affiliée à l'Université de Montréal

Digital Technology Adoption as a Factor to Build Supply Chain Resilience: The Case of an Animal-Food Supply Chain During the COVID-19 Pandemic Crisis

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Mémoire présenté en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*

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présenté par **Parham ASGHARIFARD**

en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*

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DEDICATION

This thesis is dedicated to my parents, family members and my girlfriend for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and authoring this thesis. This accomplishment would not have been possible without them.

Thank you!

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RÉSUMÉ

Plusieurs chaînes d'approvisionnement ont été gravement perturbées par la COVID-19 qui a contribué à augmenter la demande de produits alors que l'approvisionnement en matières premières se trouvait diminué. Les chefs d'entreprises ont été contraints de penser différemment et de rechercher de nouvelles opportunités pour améliorer les chaînes d'approvisionnement. Pendant la pandémie, les technologies du numérique et de la connectivité auraient pu permettre d'améliorer les chaînes d'approvisionnement en s'appuyant sur des solutions de mesure en temps réel. Cette transformation aurait pu être bénéfique pour les chaînes d'approvisionnement, en particulier pour la gestion des stocks, du transport et des contrats à l'échelle mondiale. La résilience de la chaîne d'approvisionnement fait référence à la capacité pour une chaîne d'approvisionnement à se préparer et à s'adapter à des événements inattendus en ajustant ses opérations qui affectent négativement les performances de la chaîne d'approvisionnement, puis à continuer de fonctionner tant que la perturbation perdure et de revenir rapidement à son état antérieur à la perturbation ou à un état plus souhaitable. Les technologies du numérique et de la connectivité pourraient rendre la chaîne d'approvisionnement plus résiliente et aider les entreprises à suivre le rythme des perturbations, qu'il s'agisse d'une pandémie, d'une catastrophe naturelle, de menaces géopolitiques ou d'une nouvelle réglementation industrielle. Selon l'analyse de la littérature scientifique portant sur la résilience des chaînes d'approvisionnement et les technologies numériques, il existe plusieurs documents de recherche sur la «résilience de la chaîne d'approvisionnement» et «l'industrie 4.0 et les technologies numériques». Cependant, aucune recherche n'a empiriquement lié l'adoption de la technologie à la résilience de la chaîne d'approvisionnement, qui est précisément le sujet que ce projet de recherche cherche à résoudre de manière qualitative et exploratoire.

Sujet spécifique, et il n'y en a pas de travaux qui ont lié empiriquement l'adoption des technologies à la résilience de la chaîne d'approvisionnement, ce qui est exactement l'écart que ce projet de recherche qualitatif et exploratoire cherche à résoudre. Le projet étudie si, et comment, les technologies numériques peuvent être un facteur pour favoriser la résilience de la chaîne d'approvisionnement et pour évaluer cela connexion dans le contexte du scénario de la pandémie de COVID-19. Pour y parvenir, une méthodologie basée sur des études de cas a été choisie pour effectuer une analyse qualitative des données. À la suite de cette étude qui est basée sur une chaîne d'approvisionnement

Canadienne dans le secteur alimentaire durable, et après avoir déterminer les questions de recherche initiales et la marche à suivre pour la collecte et l'analyse des données, nous trouvons des liens entre les éléments de résilience de la chaîne d'approvisionnement et lestechnologies du numérique et de la connectivité. Les résultats montrent que l’adoption, la disponibilité et la rentabilité des mégadonnées, ainsi qu'une utilisation beaucoup plus large des technologies basées sur l’info-nuagique et l'IA ainsi que la communication de machine à machine (M2M) peuvent augmenter la résilience de la chaîne d'approvisionnement et permettre aux entreprises de suivre le nouveau rythme imposé par une situation de crise.

ABSTRACT

Several supply chain networks have been severely disrupted as a result of COVID-19, which has raised product demand while decreasing raw material supply. Company managers have been forced to think differently and seek new chances to improve supply chains. During pandemics, digital and connectivity technologies could improve supply chains by enhancing real-time tailored solutions. This transformation can be beneficial to supply chains, especially when it comes to managing inventories, transportation, and contracting methods on a worldwide basis. Supply chain resilience refers to a supply chain's ability to prepare for and adapt to unexpected events by adjusting its operations that negatively affect the supply chain performance, and then to continue functioning during disruption and quickly recover to its pre-disruption state or a more desirable state. Digital and connectivity technologies could make supply chain more resilience and help companies to keep up with the rate of disruption whether it is a pandemic, a natural disaster, geopolitical threats, or new industry regulation. According to the scoping literature review which focuses on supply chain resilience and digital technologies, there are several research papers on "supply chain resilience" and "industry 4.0 and digital technologies", however, there is no research has empirically linked technology adoption with supply chain resilience, which is precisely the gap that this qualitative and exploratory research project seeks to solve. The project is investigating whether and how digital technologies may be a factor in establishing supply chain resilience and to evaluate this connection in the context of the COVID-19 pandemic scenario. To achieve this, Case study Theory methodology was chosen as methodology to conduct a qualitative data analysis. According to this study which is based on a Canadian supply chain in the sustainable food sector, after determining initial research questions and following with data collection and data analysis the results of data analysis, I find the links between supply chain resilience elements and digital technology elements. The findings show that the adoption, availability, and cost effectiveness of big data, as well as a much broader use of cloud-based technologies and AI tools with accessibility of ERP and machine-to-machine communication can increase supply chain resilience and allowing companies to keep up with the rate of disruption in a pandemic.

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LIST OF SYMBOLS AND ABBREVIATIONS

ERP…………………………………………………………………………… Enterprise Resource Planning
M2M ……………………………………………………………...……......……………Machine to Machine
IIOT ……………………………………………….………………………… Industrial Internet of Things
EoR …………………….…....………………………..……..…... Element of Resilience
CPS………………………………………………………………….........…………. Cyber Physical System
CC……………………........…………………………………………………………………Cloud Computing
AI……………………………………………………………………….....…………... Artificial Intelligence
SC..Supply Chain

LIST OF APPENDICES

CHAPTER 1 INTRODUCTION

Over the last decade, supply chain management has received considerable attention from practitioners and academics (Ray, 2016; Tang, 2006). Malfunction of one chain can lead to a series of falling in the whole supply chain. Companies are looking to improve supply chains, but they are also under pressure to manage supply chain disruption and meet the responsibility requirements associated with their supply chains. The magnitude and frequency of those disruptions in supply chains have been escalating, partly due to the globalization of supply chains and new risks presented by geopolitical and climate change issues. Over a decade, supply-chain interruptions cost the average business 45 percent of its earnings (Alicke & Luchtenberg, 2021).

The COVID-19 pandemic is one of the most severe disruptions in the supply chain in history and forces managers and academics to further explore resilience actions in supply chains. COVID-19 pandemic is today the most discussed topic in the world. Unlike past significant disruptions, it has a unique effect that adversely affected global supply chains at all levels with significant changes in manufacturing, processing, transport, and logistics, as well as significant shifts in demand (Xu et al., 2020). According to the new research (Hart, 2020), 9 in 10 global supply chains have been affected by the COVID-19 pandemic; therefore, this phenomenon is one of many disruptive events that have continuously happened worldwide. Not surprising, the impact of this pandemic on supply chains has been global, deep, and caused a series of major distortions to the logistic system of companies for instance, the cost of shipping containers has risen significantly, delivery schedules have become more erratic (Lynch, 2021). As a result, decision makers have developed different strategies to cope with this issue, and one of the solutions is the development of resilient actions. Resilience is defined as an organization's ability (in conjunction with its supply chain) to effectively develop capabilities to anticipate, adapt, respond, recover, and learn from any disruptive event alongside resource management (Iakovou et al., 2020).

Achieving resilient capability requires a set of enablers, such as a flexible and collaborative ecosystem of suppliers and partners that can handle a sudden shortage of products. Resilient supply chain is built through the development of capacity for adapting, integrating quickly, and reconfiguring internal and external organizational processes, resources, and functional competencies (Brusset & Teller, 2017; Pisano, 2015). To help achieve resilient capacity, digital technologies have the potential to reduce costs, improve visibility throughout networks and shorten response time (Ivanov et al., 2020). In this sense, Industry 4.0 and digital transformation offer a new framework for the global economy which has an impact on many industries and changes the way goods are manufactured, transported, and sold. These concepts are considered as the idea of autonomous interaction of machines, operational processes, and products within or between business firms (Ivanov et al., 2018). Recent studies show that industry 4.0 and digital technologies (such as (IoT), Cyber-Physical Systems (CPS), Cloud Computing, Big Data and Blockchain, Artificial Intelligence (AI), Augmented Reality, ERP, CRM) not only improve supply chain performance but also enable companies to improve their supply chain resilience (Ambulkar et al., 2014).

Industry 4.0 and digital technologies can help develop e agile actions by offering a comprehensive approach to supply chain management as a result of broad supply chain integration, information exchange, and transparency operations that are more capable of responding to disruption and quicker recovering from disturbance. Analytical data-driven models, simulation, and end-to-end transparency enable managers to design effective and resilient supply chains digital technologies add advantages to the supply chain, specifically in managing inventory, logistics, and contracting sector on a global scale; digital technological features are particularly related to visibility, information sharing, and agility, which are some of the most essential aspects of resilient supply chains.

In this context, the research question to explore is whether and how digital technologies may contribute to developing supply chain resilience and analysis of the relationship. To achieve this purpose, a case study was conducted to allow the understanding of how the companies from a Canadian pet-food supply chain dealt with the COVID-19 pandemic through digital technologies to build resilience. Case study is a research approach concerned with the development of theory that is in evidence that has been collected and analyzed methodically (Yin, 2017). Following a review of the literature to identify important themes linked to resilience, supply chain, and digital adoption models and an open and semi-structured interview guide assist researcher in gathering enormous and comprehensive information regarding how supply chains change to the COVID-19 pandemic and the role that digital technology had in that effect. Furthermore, the interview allows the study team to categorize the supply chain scenarios based on their resilience and digital adoption. The data gathered during interviews is transcribed and then examined using content analysis techniques to identify trends in respondents' interviews.

The structure of the thesis is the following. The first chapter introduces the research. Chapter two is a comprehensive (but not systematic) literature review on the topics that concern this research, namely: digital technology adoption and supply chain resilience. Chapter three presents the research methodology. The results are then presented in chapter four and discussed in chapter five. Finally, chapter six presents the conclusions of the research, its limitations and makes suggestions for future studies in the topic.

CHAPTER 2 LITERATURE REVIEW

During the COVID-19 crisis, the need to have a prominent level of supply chain resilience was stressed. The capacity to measure and monitor supply chain events, recognize patterns, and proactively transform these insights into actions is more important than ever in order to develop supply chain resilience. Digitization is transforming a formerly segmented supply chain into an integrated end-to-end digital ecosystem from raw material procurement through production and shipping, and finally to consumer satisfaction. The ideas of organizational resilience and supply chain technology are discussed in this section. Additionally, digital technologies and the effects of it on organizational resilience in the following part first describe the element of resilience then digital technologies and finally the relation of digital technologies and the supply chain resilience. For literature review I applied scoping literature review which is an exploratory research project that carefully map the literature on a topic by finding key concepts, hypotheses, and sources of evidence that impact field practise in this review specifically supply chain resilience, digital technologies and impact of that on supply chain resilience.

2.1 Supply Chain Resilience

The word "resilience" initially came from materials science, alluding to a system's capability to recapture its initial state after experiencing versatile distortion without any alter in its nature (Ponomarov & Holcomb, 2009). Currently, resilience is described as an organization's capacity (in cooperation with its supply chain) to successfully establish capacities to predict, adapt, respond to, recover from, and learn from any disruptive event while also managing resources and it ensures the supply chain's performance and long-term viability. (Iakovou et al., 2020). Resilient organizations are able to handle supply chain disturbances when they happen and note that the capacity to adjust is key to resilience (Ivanov et al., 2018). Bode et al. (2011) characterize this provision in the corporate environment as a condition of alertness, awareness, seriousness, and acknowledgment of learning possibilities coming from moments of rupture. As a result, the firm will reach a point (rupture) where it will have to reassess the efficacy of its operations, behaviours, strategies, and organizational structures. Organizational resilience is defined by Pettit et al. (2013) and Kamalahmadi and Mellat-Parast (2015) as a company's ability to endure, adapt, and growth in uncertain and changeable conditions. Given the real and current market volatility, as well as the incidence of environmental and human calamities, it is clear that in general this idea is critical for operational management (Scavarda et al., 2015).

It was common manner for decision makers to respond disruptions reactively (post-event decision-making) while proactive decision-making necessitates that decision makers consider future consequences that may follow from their choices, as well as that they be aware of and understand how to use helpful resources to assist them succeed. The better organized, on the other hand, are already building continual plans and processes to reduce the consequences of unanticipated occurrences in advance (pre-event decision-making), as well as generating adaptable and inventive solutions (Kamalahmadi & Mellat-Parast, 2015). Parker and Ameen (2018) add to this by adding that as soon as an organization recognizes its weaknesses, it becomes more aware of its vulnerabilities and begins to prepare for more responsive/resilient measures. In this regard, companies should be proactive in order to obtain better results (Breur, 2016).

Capacity to respond to supply chain disruptions via a collaborative strategy and understanding how to organize a quick reaction. The most challenging task for managers is to enable collaborative setting (Werner et al., 2020). The other findings validated the suggested collaboration index measure's reliability and validity as a tool for evaluating cooperation. The cooperation index was also shown to be highly linked with operational performance (Simatupang & Sridharan, 2005). Vertical and horizontal cooperation are the two most common kinds of supply chain collaboration. Vertical collaboration exists when two or more organizations from various levels or stages of the supply chain share responsibilities, resources, and performance information in order to serve relatively similar end customers; horizontal collaboration, on the other hand, is an inter-organizational system relationship between two or more companies at the same level or stage of the supply chain in order to allow greater ease of work and cooperation towards a common goal. Chan and Prakash (2012) and there are a lot of rupture stems in the present literature (Bode et al., 2011; Parker & Ameen, 2018; Pereira et al., 2020). Examples of recurring ruptures include a scarcity of raw materials, mechanical breakdowns, inventory and production planning communication problems, sales forecasting errors, and changes in the work environment owing to the Covid-19 Pandemic, among others. What makes a corporation resilient, on the other hand, is its capacity to recognize how to respond to adversity by combining internal and external resources. The elements of resilience (EoR) identified in the literature serve as the foundation for developing resilient organizational actions and practices (Ali et al., 2017). Resilient supply chains have common characteristics: agility, digitization and connectivity, ability to recover rapidly and responsiveness (Terblanche, 2021). For organizations, robustness is defined as a system's ability to maintain its predefined qualities in the face of known and unknown disruptions. (Telmoudi et al., 2008).

The concept of resilience is developing effective capabilities for predicting, adapting, responding, recovering and learning from past disruptive (Pereira et al., 2020). The system ability to adapt and reconfigure is a key feature in supply chain resilience. Ivanov et al. (2020) in the following part, the main elements of resilience including Agility, Collaboration, Information sharing, Trust, Flexibility, Financial Strength, Risk Management, Knowledge Management and Redundancy are described.

Supply Chain Resilience is the supply chain's adaptive capacity to respond to unforeseen occurrences, respond to disturbances, and recover from them. The Covid19 pandemic's lessons have emphasized the significance of a robust supply chain to all organizations. Building a robust supply chain is dependent on several key elements of resilience, including Agility, Collaboration, Information Sharing, Trust, Flexibility, Financial Strength, Risk Management, Knowledge Management, Redundancy, Robustness, Visibility, Safety, Supply Chain Design which describes in the following part.

Agility – In the context of manufacturing, the term agility refers to adaptable production systems. Agility has begun to be addressed as a competitive strategy to dynamic situations, while organizational procedures have been updated. Capacity to react rapidly to changes, possibly reducing the effect of a potential interruption. One of the properties of an agile supply chain is the ability to boost speed in order to respond to changes (Werner et al., 2020). Agility is a crucial supply chain quality required for survival in turbulent and unpredictable markets, which are becoming the norm as product life cycles shorten and environmental influences cause more uncertainty, resulting in increased supply chain risk. Agility also aids in delivering the right product to the right customer at the right time, which is the primary goal of any supply chain (Agarwal et al., 2007). Furthermore, enterprises must connect with suppliers and customers to coordinate operations and attain a degree of agility beyond that of rivals in order to gain a competitive edge in the fast-changing business environment (Lin et al., 2006).

Collaboration – Supply chain collaboration is defined as two or more independent enterprises working together to plan and execute supply chain activities due to complexity dynamics of supply chains, their organizations must establish collaborative strategies including all roles and departments inside the system's enterprises (Werner et al., 2020). It has the potential to provide significant benefits and advantages to partners (Cao & Zhang, 2010). Capacity to respond to supply chain disruptions via a collaborative strategy and understanding how to organize a quick reaction. The most challenging task for managers is to enable collaborative setting (Werner et al., 2020). The other findings validated the suggested collaboration index measure's reliability and validity as a tool for evaluating cooperation. The cooperation index was also shown to be highly linked with operational performance (Simatupang

& Sridharan, 2005). Vertical and horizontal cooperation are the two most common kinds of supply chain collaboration. Vertical collaboration exists when two or more organizations from distinct levels or stages of the supply chain share responsibilities, resources, and performance information in order to serve relatively similar end customers; horizontal collaboration, on the other hand, is an inter-organizational system relationship between two or more companies at the same level or stage of the supply chain in order to allow greater ease of work and cooperation towards a common goal (Chan & Prakash, 2012).

Information sharing – this is a critical strategic element for business sustainability and a key facilitator of supply chain integration. Information sharing has grown increasingly feasible in recent years as information and communication technology has advanced. Additionally, the global development of long-term collaboration and coordination has improved the efficiency of information exchange in supply chains, resulting in an increase in enterprises' competitiveness (Lotfi et al., 2013). Information sharing is the key principle to mintage risks in the supply chain (Christopher & Peck, 2004). They believe that cooperation needs members to communicate information and data effectively and efficiently, and that this information plays a crucial role before and after supply chain interruptions. Furthermore, exchanging knowledge aids in identifying possible or imminent difficulties. Managers should be able to make more forceful decisions as a result of this aspect of resilience, enhancing the supply chain's profitability. As a result, information sharing may be characterized as resource use based on reciprocal visibility of operations (Karl et al., 2018).

Trust – Based on the assumption that partners do not act opportunistically, even if there are short-term incentives to do so, hence contributing considerably to the organization's and supply chain's long-term stability. Information sharing raises the trust topic, which enhances transparency inside businesses. Its purpose is to outperform enterprises that work alone in terms of operational performance. As a result, supply chain partners must have believed in one another in order to encourage collaboration, dispute resolution, and decision-making in the face of uncertainty and potential interruptions. As a result, trust is earned by behaviours made in the face of expectations that supply chain partners would prioritize joint interests, avoiding greed and opportunistic behaviour throughout the negotiating process (Brusset & Teller, 2017).

Flexibility – this element is defined as the ability to adjust to changing circumstances, whether through procedures, resources, goods, pricing, or transportation. In this regard, experts emphasize that flexibility refers to an organization's capacity to re manage its output in a cost-effective manner within a given time frame and interval. Organizations must be adaptable in order to deal with important levels of adversity. In other words, these businesses must match consumer expectations without increasing expenses, causing significant disruption, or compromising performance. As a result, flexibility is defined as the capacity to realign operations or plans in response to changing market demands while maintaining the company's and its activities' efficiency (Ali et al., 2017; Sahu et al., 2017).

Financial strength – it refers to the ability to withstand cash flow variations, which has an impact on acquisition activity. Financial strength is described as the capacity to resist profitability variations, whether through insurance (for facilities, equipment, goods, and people), financial reserves (to meet anticipated demands), portfolio diversification, or pricing margin. This aspect of resilience is also related to firms who have a strong market position, since they can rely on a margin to invest in robust supply chains, allowing them to maintain a healthy connection with consumers in the event of a disruption. As a result, firms with financial strength are able to endure periods of increased economic instability while preserving the acquisition of their operations and goods (Pettit et al., 2013; Ali et al., 2017).

Risk management – Any risk to the integrity of information, materials, products, and process flowing along the supply chain is referred to as a supply chain risk. In this regard, proper techniques should be implemented in a coordinated manner from raw materials through product delivery in order to mitigate any risks that businesses may have. Risk management is a reaction to high-unpredictability disturbances in the past, present, and future. As a result, when selecting which risks should be mitigated, minimized, or managed, its implementation tries to organize risk identification and measuring methods in order to maintain better responses. As a result, risk management is used in this work to define methods that are in place to identify, analyze, prevent, and/or counter hazards to the industrial process's stream (Ponomarov & Holcomb, 2009).

Knowledge management – It describes the methods for capturing information and experiences from lessons learnt, so that knowledge may be retained in the company's file rather than only in the minds of employees. Through gained experiences, such as training and information exchange, this seeks to assist managers in overcoming various forms of disruptions. In other words, the capacity of a corporation to enhance the exchange of knowledge among its individuals is known as knowledge management. The collection, storage, dissemination, and application of knowledge are the four basic processes of this talent. A robust supply chain leverages knowledge management to prepare for potential disruptions through training and team training, resulting in a resilient corporate culture.

Similarly, its purpose is to make it easier for managers to deal with a range of disruptions once they have learnt from their mistakes, which they should ideally document. As a result, knowledge management is defined by recording, reuse, and access to information that can assist in the development of resilient strategies in the face of potential ruptures (Gonzalez, 2017; Gonzalez & Martins, 2017).

Redundancy – Expanded manufacturing, transportation, stock, and storage capacity that can aid in critical moments like supply disruptions (Christopher & Peck, 2004). One option for overcoming the disturbances is to build resource redundancy across the supply chain. Although managers must evaluate the risks and costs of resource redundancy, this method can be advantageous in combating organizational disruptions. This capability makes it simpler for businesses to respond with unanticipated events like supply disruptions by examining the short- and long-term costs involved with decision-making. During these circumstances, redundancy gives management more time to make an informed decision. The increased volume of supply chain resources, whether from manufacturing, inventory, transportation, or storage installation, which gives businesses with the ability to maintain scarce moments, is described by this bias (Karl et al., 2018). These additional resources may come from secondary suppliers, alternate logistic modals, or spare industrial capacity, according to the report. As a result, redundancy is defined as an excess of productive resources that may be beneficial in the event of a disruption in the flow of production (Werner et al., 2020).

Robustness – The ability of a supply chain to overcome the effects of various interruptions or to preserve process continuity. Developing resilience allows businesses to maintain their operational effectiveness while avoiding larger interruptions. Scholten et al. (2014) characterize robustness as the ability of a supply chain to endure change without having to modify its original, stable structure. In this way, this chain sustains and continues its activities despite the disruptions it encounters, considering the range of situations in which the chain responds appropriately without changing its design. As a result, robustness is defined in this paper as an organization's level of resilience to eminences and rupture events (Pereira et al., 2014).

Visibility – Access to information related to inventory conditions, demands, and supplies in the chain in general is referred to as visibility. Its purpose as a component of resilience is to estimate supply and demand, enabling management to determine what factors influence the company's financial success. Furthermore, it emphasizes that visibility is gained and increased by performance indicators to track organizational assets, both real and intangible, such as goods and processes (Werner et al., 2020). As a result, visibility is defined as the capacity to identify dangers and events that might harm an organization's or supply chain's performance (Karl et al., 2018).

Safety – Given the serious impact of supply chain disruptions, security management is vital for success. In this regard, from the beginning to the end of the chain, guidelines, processes, and technology applications must be used to manage the safety of commodities, whether they are products, facilities, equipment, or even information. Security is the component that informs supply chains about potential physical or cyber threats. As a result, security is defined by a company's approach, which prioritizes detecting risks and safeguarding its goods, facilities, and equipment (Werner et al., 2020).

Supply chain design – Fracture events are predicted by a well-planned supply chain that has been prepared for adversity. Therefore, the authors describe chain arrangement as an adaptive strategy to deal with disruptions, to function reliably following events, and, if feasible, to obtain a competitive edge. Furthermore, this capability decreases the chain's complexity and enhances flow. Reconfiguring supply chains in the face of change makes them more durable, secure, and agile. As a result, the chain's configuration is defined as the alignment and ongoing rebuilding of processes and strategies in order to adapt to the unexpected while maintaining the chain's operations' continuity (Ali et al., 2017; Karl et al., 2018).

The benefits of developing a resilient company are enormous. The "resilient" supply chain is not only able to resist all types of disruption but also be able to boost its competitiveness. Unexpected interruptions might cause shortages comparable to demand spikes caused by supply/demand imbalances; resilient companies can thus respond to shifting market demand ahead of their competitors. In previous section I describe the essential elements of resilience in the following part I define the digital technologies which could improve the supply chain resilience and later on I discuss about their relations.

2.2 The concept of Industry 4.0 and digital technologies

The modern manufacturing industry is entering the fourth wave of technological advancement. Industrial changes have exhibited substantial technical innovation to increase the production efficiency of manufacturing organizations in recent years. Different industrial transformation including Industry 1.0, Industry 2.0, and Industry 3.0, respectively, convert the steam power into industrial operation power, and then the use of electrical power, finally use of information technology as a data-driven force for operation (Chouhan et al., 2017; Vinodh & Wankhede, 2020). According to the theory of conception, there were series of the transformation of industry and the first industrial change was marked by mechanization, as evidenced by the advent of the steam engine. The mass manufacture of goods on assembly lines based on electricity was the second industrial revolution. The automated manufacture of industrial robots was the third industrial mutation (Ahuett-Garza & Kurfess, 2018). The fourth industrial phenomena have changed traditional manufacturing processes. Industrial manufacturing moves towards a more digitized, customized, agile, and efficient both in operation and supply chain network beside other advancements such as lean manufacturing. Industry 4.0 and digital technologies make integration of information and communication technologies (ICT) with automation technologies for improving end-to-end systems integration in the value chain (Lechler et al., 2019). The term "industry 4.0 and digital technologies" is a collective name for technology and value chain organization concepts, with implications for value generation, organizational performance, the development of new business models, services, and work structure (Hermann et al., 2016; Lechler et al., 2019; Lichtblau et al., 2015; Schwab, 2016; Xu et al., 2018). Hermann et al. (2016) set four principles for designing Industry 4.0: interconnectivity, information transparency, decision decentralization and technical assistance. The concept of Industry 4.0 and digital technologies is built on the integration of information and communication technologies with industrial technology in order to create an intelligent and digital factory that promotes information-driven manufacturing. Industry 4.0 is defined as a “Generic strategy relying on connectivity and digitization through the use of various technologies in order to transform processes, products and services with decentralized real-time decision-making and giving rise to new capabilities, in cooperation with humans, ranging from system monitoring to control, optimization and autonomy’’ (Danjou et al., 2017).

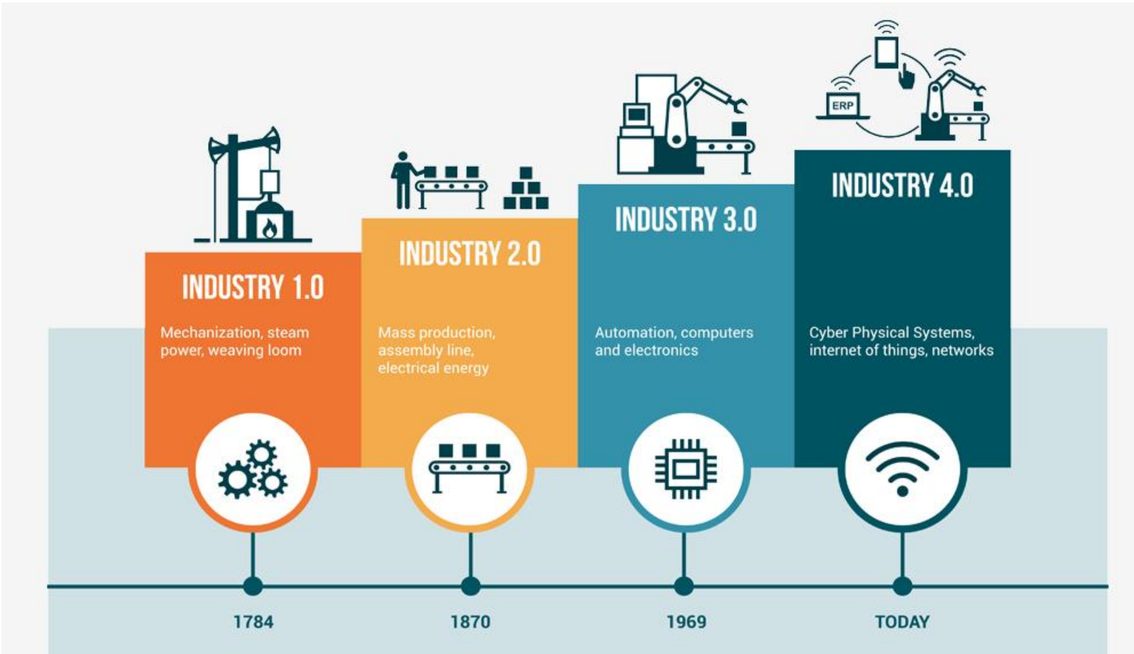

Figure 2-1 Industry Revolution (Yadin, 2021)

Industry 4.0 and digital technologies have activated the necessity of development and innovation, individualization of demand, and resource efficiency (Dwivedi et al., 2020). The term Industry 4.0 and digital technologies are related to the technology development and the digitalization process that improve productivity significantly and create possibilities for lowering the production cost with improving the efficiency the result appears in competitiveness. Li et al. (2017), classified Industry 4.0 and digital technologies in three dimensions: (1) integration and technological advances (2) internet and scaling of the data access (3) combine of cyber physical and human interactive technologies. With the introduction of Industry 4.0 and digital technologies, the industries are facing sophisticated technical advancements. Digital technologies encompass several technologies, mainly including the Internet of Things or Industrial Internet of things (IIoT), Cyber-Physical Systems (CPS), and Big Data, cloud computing, additive manufacturing, and augmented reality, Artificial Intelligence (AI). Finally, ERP as the enabler technology to digital technologies with integrated management of core business processes and increase the efficiency and visibility in the company and operation ERP II was coined in 2000 and it refers to web–based software that offers personnel and partners with real–time access to ERP systems (such as suppliers and customers). The ERP II function enhances the classic ERP roles of resource optimization and transaction processing. Rather than only managing purchasing, selling, and so on—ERP II uses information in the resources under its administration to assist the organization in collaborating with other enterprises. (Moller, 2005). In the following some of the most important technologies are described and the relation of those technologies and supply chain resilience is later discussed.

Internet of Things - Internet of Things (IoT) is a concept that indicates the link between the digital and physical worlds (Atzori et al., 2010). The Internet of Things (IoT) defines physical items (or groups of such objects) equipped with sensors, processing capability, software, and other technologies that connect and exchange data with other devices and systems through the Internet or other communications networks (Gillis, 2022). The Internet of Things is a component of the Future Internet and can be defined as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols, in which physical and virtual "things" have identities, physical attributes, and virtual personalities, as well as intelligent interfaces, and are seamlessly integrated into the information network. On the Internet of Things, "things" are expected to become active participants in business, information, and social processes, allowing them to interact and communicate with one another and with the environment by exchanging data and information "sensed" about the environment, as well as reacting autonomously to "real/physical world" events and influencing them through running processes that trigger actions and create services with or without direct human intervention. Interactions with these "smart objects" over the Internet, including querying and changing their status and any information linked with them, are facilitated through interfaces in the form of services, which take security and privacy concerns into consideration (Sundmaeker et al., 2010). Digital transformation is often cited as an alternative to overcome the crisis in many domains, including commerce (Sharma et al., 2020), education (Secundo et al., 2021), health care (Gunasekeran et al., 2021) and urban services (Allam & Jones, 2021), to name a few. Technology specifically industry 4.0 and digital technologies enable managers to decide effectively and accurately in the disturbance. The industrial internet of things (IIoT) is a term that refers to interconnected sensors, instruments, and other devices that are networked with industrial applications on computers, such as manufacturing and management. Data gathering, sharing, and analysis are all possible with this connectivity, which leads to increase production and efficiency, as well as other economic and environmental benefits (Boyes et al., 2018). The IIoT is an evolution of a distributed control system (DCS) that uses cloud computing to enhance and optimize process controls, allowing for a higher degree of automation. In the manufacturing industry, the terms "industrial internet of things" IIoT is frequently used to refer to the IoT's industrial subset. Improved efficiency, analytics, and workplace change are among potential benefits of the industrial internet of things. IIoT systems have a layered modular digital technology architecture (Yoo et al., 2010). The physical components, such as CPS, sensors, or machines, are referred to as the device layer. The network layer, which consists of physical network buses, cloud computing, and communication protocols that aggregate and transfer data to the service layer, which consists of applications that manipulate and combine data into information that can be visualized on the driver dashboard, is made up of applications that manipulate and combine data into information that can be displayed on the driver dashboard. The content layer, often known as the user interface, is at the top of the stack (Hylving & Schultze, 2013). IIoT architecture may be thought of as a system that consists of a collection of various active physical items including sensors, actuators, cloud services, special IoT protocols, communication layers, users, developers, and enterprise layer, which can be physical, virtual, or a combination of them (Ray, 2016).

Table 2-1 IIoT Architecture Layers

Content Layer	User interface devices (Computers, tablets, Augmented reality glasses)
Service Layer	Applications, software to data analysis and transform it into actionable information, Cloud data services
Network Layer	Communications protocols, Wi-Fi, Bluetooth, LoRa, cellular
Device Layer	Hardware: CPS, machines, sensors, actuators

Cyber-Physical Systems - Cyber Physical Systems (CPS) are systems that integrate computers, networking, and physical processes. Embedded computers and networks monitor and regulate physical processes through feedback loops in which physical processes influence computations and likewise (Lee & Seshia, 2016).

The five level CPS architecture includes various levels in the first layer which is named smart connection in designing a Cyber-Physical System application is to collect precise and accurate data from machines and their components. The data might be measured directly by sensors or received via controllers or corporate manufacturing systems like ERP, MES, SCM, and CMM (J. Lee et al., 2015). The next layer is conversion. At this level, data must be interpreted to yield meaningful information. There are now various technologies and approaches available for data to information conversion. In recent years, much effort has gone into developing these algorithms expressly for prognostics and health management applications. The cyber level serves as a crucial information centre, information is being pushed to it from all directions. Machines are linked together to form a network. Massive amounts of data must be acquired, and particular analyses must be performed, in order to extract more data that provides better results awareness of the status of specific machines among the fleet. In cognition level results in a full understanding of the monitored system. The correct decision is supported by the proper presentation of obtained knowledge to expert users. Because comparison data as well as individual machine status are available, decisions on job prioritization may be made to improve the maintenance process. The configuration level provides input from cyberspace to physical space and serves as supervisory control to allow machines to self-configure and self-adapt. This stage functions as a resilience control system (RCS) to implement corrective and preventative actions taken at the cognitive level to the monitored system (J. Lee et al., 2015).

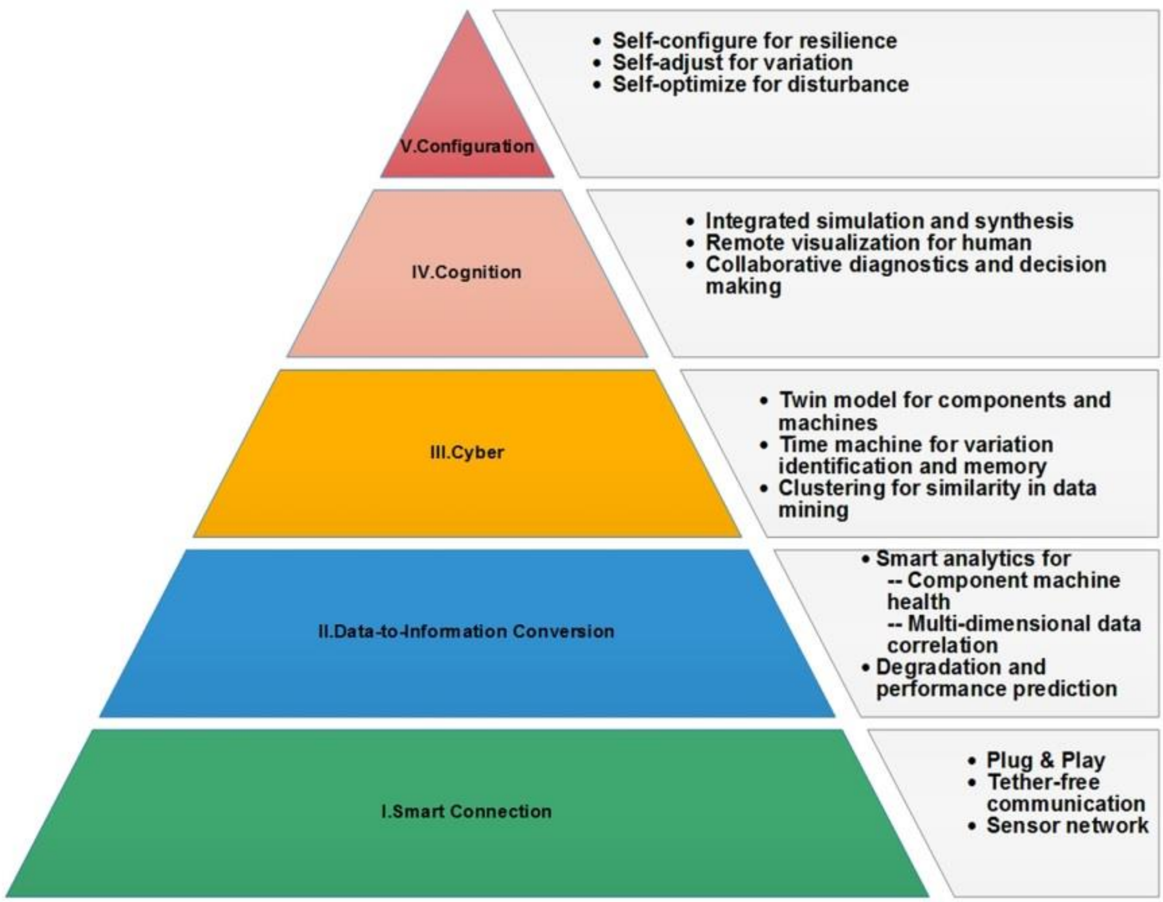

Figure 2-2 The CPS 5C Architecture

(Lee J, 2015)

Artificial Intelligence - Artificial intelligence (AI) was first coined in 1956, but thanks to increased data volumes, advanced algorithms, and advances in computing power and storage, AI is becoming more popular today. AI is defined as the capacity of a digital computer or a computer-controlled robot to do tasks that would normally be performed by intelligent individuals. The phrase is widely used to refer to a mission designed to generate systems with human-like cognitive abilities, such as the capacity to reason, discover meaning, generalize, and learn from prior experiences. It has been proved that computers can be programmed to perform extremely complicated functions since the introduction of the digital computer in the 1940s (Copeland, B.). Leading AI textbooks describe AI as the study of "intelligent agents," or systems that understand their environment and take actions that increase their likelihood of achieving their objectives (Bartneck et al., 2020). Machines may learn from their experiences, adapt to new inputs, and execute humanlike jobs thanks to artificial intelligence (AI). Most AI examples that we hear about today rely largely on deep learning and natural language processing, from chess-playing computers to self-driving automobiles. Computers may be trained to do certain jobs by analyzing massive volumes of data and identifying patterns in the data using these methods.

Cloud computing - Cloud computing is a concept for providing on-demand network access to a shared of customizable computing resources (e.g., networks, servers, applications, and services) particularly data storage (cloud storage) computational power that could be instantly supplied and released with no administration effort or service provider involvement (Montazerolghaem et al., 2020). Cloud services providers provide their "services" in a variety of models, with Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) being the three basic types according to NIST (Mell & Grance, 2011). Based on NIST definition SaaS is given the ability to use the provider's applications that are hosted on a cloud architecture. The app can be accessed via a flexible client interface, such as a web browser (e.g., web-based email), or a programmed interface, via a variety of client devices. Apart from restricted user-specific application configuration choices, the customer does not manage or control the underlying cloud infrastructure, which includes network, servers, operating systems, storage, or even individual application capabilities. Users can access application software and databases using the software as a service (SaaS) concept. The infrastructure and platforms that operate the apps are managed by cloud providers. SaaS is also known as "on-demand software," and it is often charged on a pay-per-use or subscription basis (PCMag, 2022). The National Institute of Standards and Technology (NIST) define PaaS is given to the customer the power to deploy consumer-made or acquired applications written with programming languages, libraries, services, and tools supported by the provider into the cloud infrastructure. The customer has no control over the underlying cloud infrastructure, such as the network, servers, operating systems, or storage, but do have control over the installed apps and maybe the application-hosting environment's configuration settings. PaaS companies provide application developers with a development environment. The definition of IaaS according to NIST where the user could install and run any software, including operating systems and apps. Although the customer does not manage or control the underlying cloud infrastructure, he or she does have control over operating systems, storage, and installed applications, as well as maybe limited control over some networking components.

Big data - Big data is a discipline that deals with methods for analyzing, rationally extracting knowledge from data, or otherwise dealing with data volumes that are too massive or complicated for typical data-processing application software to handle. Data with a lot of columns has more statistical power for pattern recognition. However, data with a lot of columns has a higher false discovery rate (Breur, 2016). Big data often refers to data volumes that are too large for standard software tools to acquire, curate, manage, and processes within a reasonable amount of time (Schneider, 2018). Big data involves a combination of approaches and technologies, as well as new kinds of integration, in order to extract insights from large, diverse, and complicated data sets. To infer laws (regressions, nonlinear correlations, and causal effects) from massive collections of data with low information density, big data employs mathematical analysis, optimization, inductive statistics, and techniques from nonlinear system identification (Billings, 2013).

Augment Reality - Augmented reality (AR) is an interactive experience of a real-world environment in which computer-generated perceptual information is used to augment the items in the real world, sometimes spanning many sensory modalities such as visual, aural, haptic, somatosensory, and olfactory (Williams, 2017). Augmented Reality (AR), and specifically Industrial Augmented Reality (IAR), is one of the technologies that can assist operators with tasks such as assembly, context-aware assistance, data visualization and interaction (acting as a Human-Machine Interface (HMI)), indoor localization, maintenance applications, quality control, and material management (Fraga-Lamas et al., 2018).

Cyber Security - The technique of securing critical systems and sensitive data against cyber-attacks is known as cybersecurity. Cybersecurity measures, also known as information technology (IT) security, are meant to prevent threats to networked systems and applications, whether they come from within or outside of a company (Schatz et al., 2017). Due to the growing reliance on computer systems, the Internet, and wireless network standards such as Bluetooth and Wi-Fi, as well as the growth of "smart" devices such as smartphones, televisions, and the various technologies that make up the "Internet of things," the field is becoming increasingly important. Because digital and linked technologies create a massive amount of data, which is subsequently transferred for instance transfer to the cloud-based platforms, cyber-security is a big challenge in Industry 4.0 and digital technologies. To address the special demands of cyber security concerns, new protocols such as block chains are being established.

Simulation- Simulations are digital models that simulate the activities or processes of a system in computing. These simulations are used to analyze system performance as well as to test and implement innovative ideas. Engineers and professionals utilize simulations to test goods, systems, processes, and concepts in a range of sectors. Industry uses simulations to test products, systems, processes, and concepts. Simulations are digital models created with computer-aided design software tools and are frequently utilized throughout the design phase. These models can illustrate aspects of a process or product in 2D or 3D, but they can also be built using mathematical principles rather than computer-based representations (Borrelli & Wellmann, 2019). Simulation is the process of creating a model of a real or abstract system in order to explain and study the system's behaviour (Galvão Scheidegger et al., 2018). Mathematical models are critical for product design, production planning, and material flow processes, as well as in the modelling of unanticipated stochastic occurrences. Simulation is employed more frequently in plant operations in the future. Simulation is a method of observing the actual world in a virtual environment, which can include machinery, equipment, goods, and people. It is a useful tool for maximizing resource use and optimizing production (Kovács et al., 2019). Since the traditional systems are simple, they are not able to handle the complexities of new supply chain risk Pettit et al. (2019) therefore for coping to the new risks managers should apply new techniques for controlling the supply chain performance. There are series of papers which link the industry 4.0 and digital technologies and resilience in the supply chain. While connection and data collection are necessary for IIoT, they are only functions of IIoT. Integration of Internet-connected including sensors and actuators systems can help to reduce overall energy usage (Romascanu et al., 2015). IoT devices are projected to be integrated into all types of energy-consuming equipment (switches, power outlets, lamps, televisions, and so on) and be able to interact with the utility supply business in order to perfectly balance power generation and energy consumption (Parello et al., 2014).

Machine Autonomy- Advances in information and communication technology open up enormous possibilities for supply chain intelligence and autonomy, providing a basis for Industry 4.0 and digital technologies supply chains (SCs) (Ghadimi et al., 2019). According to Industry 4.0 and digital technologies, the future of production is ubiquitous integration, in which all industrial parts autonomously communicate information, trigger operations, and control themselves (Pramanik et al., 2019). Machines are becoming increasingly autonomous and collaborative. Intelligent machines can communicate with one another to increase productivity and productivity. These machines are capable of doing more difficult tasks and dealing with unanticipated issues.

Machine to Machine Communication (M2M) - M2M refers to the technologies that allow computers, embedded processors, smart sensors, actuators, and mobile devices to communicate with one another, collect measurements, and make decisions without the need for human interaction, autonomous equipment that can interact in real time and collaborate with other smart devices in a smart environment, making choices and taking actions depending on the data gathered. Machine-to-machine (M2M) communication occurs when devices communicate directly with one another through any data transmission, including wired and wireless. M2M has a practically limitless number of uses. One example is traffic control, which involves devices exchanging data in order to control traffic flow. Security systems, vending machines, and data harvesting are among the others (OECD Digital Economy Papers, 2012).

Additive Manufacturing -The ASTM society defines additive manufacturing (AM) as “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies” (ASTM F2792) known as additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and free-form fabrication. Design/modelling, fit and function prototyping, and direct component manufacturing is the most common uses of additive fabrication. AM is revolutionizing the way companies develop and create things all around the world. It could save a significant amount of time and money when utilized appropriately. Companies claim that AM has reduced design, prototype, and production time, while avoiding costly errors and improved product quality (Leary, 2020). Traditional manufacturing processes require shaping a material into the required shape by removing pieces of it in a multitude of ways. Additive manufacturing is the opposite; structures are created by building hundreds of microscopic layers together to form the final result. The process requires the use of a computer and specific CAD software that can send signals to the printer, enabling it to "print" in the desired shape. The cartridge, which may be used with a variety of materials, is filled with the required substance, which is then "printed" into the form one wafer-thin layer at a time. These layers are fused together as they are continually printed on top of each other until the form is complete (Tempelman et al., 2014). 3D printing, rapid prototyping (RP), direct digital manufacturing (DDM), and additive fabrication are all subsets of additive manufacturing. The possibilities for AM applications are endless. Rapid prototyping was the first use of AM, and it was utilized to create pre-production visualization models. AM is already being employed to develop end-use objects in airplanes, dental restorations, medical implants, vehicles, and even fashion.

In the previous section I found that Industry 4.0 and digital technologies currently assist businesses in transitioning from digitization to a company-wide, competitive business strategy that combines factory automation with enterprise business execution. This involves intelligent product engineering, intelligent factory management, and asset exploiting advanced logistics in conjunction with people empowerment. Industry 4.0 and digital technologies integrate design, manufacturing, delivery, and operation solutions into a single holistic offering, bringing enterprise business data together with data derived from machines, sensors, and devices, enabling the ability to automate processes with embedded artificial intelligence and increase visibility and efficiency. In the next section I discussed the relation of industry 4.0 and digital technologies and supply chain resilience.

ERP (Transition Technology) - Enterprise resource planning (ERP) as a transition technology to fully digitalize supply chain is an initial for enterprise resource planning (ERP). It is an element of business process management software that manages and connects a company's finances, supply chain, operations, commerce, reporting, manufacturing, and human resource functions. ERP is the integrated management system of key business operations, which typically exchanges data in real time and managed by software and technology. ERP is a type of business management solutions a set of linked applications that allows a company to gather, store, manage, and understand data from a variety of business processes. ERP software appears to have progressed significantly in its software development section during the beginning of the 2000s. From this time the entire system was deployed through the internet. Furthermore, the ERP software was able to interact with a variety of other applications even back then. These were largely intended to be utilized by businesses from a single platform. And the ERP system has grown much more in recent years. ERP systems are now primarily cloud-based. Furthermore, businesses are adopting the ERP system in conjunction with the Software as a Service (SaaS) concept. ERP systems can be local or on the cloud. Most businesses have some sort of financial and operational system in place, but most of the software available cannot help with future business growth or go beyond ordinary business activities. Using shared databases managed by a database management system, ERP gives an integrated and continually updated picture of fundamental company activities. ERP systems keep track of a company's resources cash flow, raw materials, and production capacity as well as the status of orders, purchase orders, and payroll. The system's applications distribute data among the many departments that provide it (manufacturing, purchasing, sales, accounting) (Almajali et al., 2016).

Figure 2-3 ERP (L., 2019)

Traditionally, information is centrally maintained in a single database, which serves as a centrepiece for recording, sharing, and distributing information across many business divisions. Cloud-based ERP solutions have altered the way systems are sold, acquired, actualized, used, maintained, advanced, and even resigned. In a cloud-based innovation, The Software as a Service (SaaS) model of service is used to deliver cloud ERP solutions. In a cloud, the service provides clients with access to a system, hardware, and storage space, with system and hardware administration made extremely simple for the clients. The motivation for organizations to use an ERP system is often to reduce costs, improve decision-making through better reporting capabilities, strengthen customer relationships, satisfy market and regulatory requirements, and boost process productivity (Zerbino et al., 2021). With a cloud-based ERP system, companies now could access web client real time data through the Internet. Similarly, the service provider is responsible for updating, supervising servers, maintaining them, and performing backups. Finally, the cloud ERP service provider ensures the system's security, reliability, and constant operation for the advantage of its client users (Bjelland & Haddara, 2018).

Figure 2-4 Benefit of Cloud ERP Systems (Egbon, 2020)

In this part the digital technologies describe in the following part the relation of digital technology and supply chain define.

2.3 The impact of digital technology on supply chain resilience

Digital technologies enable companies to understand and activate other sources of supply; improve visibility of inbound materials; prioritize production schedule agility; and analyze alternative outbound logistics options and secure capacity. validate the plan for short-term demand-supply synchronization; Prepare for probable channel shifts; establish communication channels with consumers; and do global scenario planning. (Breur, 2016). Accordingly, organizations with higher levels of digital technology implementation are likely to be more flexible (Fletcher & Griffiths, 2020) when it comes to reacting to unpredicted events. Recent technological progress, especially industry 4.0 technologies, makes it possible to improve supply chain resilience in some disruption such as the COVID-19 pandemic.

The Covid-19 pandemic displayed the importance of transparency and visibility to improve supply chain resilience. The negative aspect of modernization is that companies now do not completely comprehend the complex aspects of Industry 4.0, and as a result, they are unsure of what it means to them (Bibby & Dehe, 2018). They have difficulty defining their current stage of development in relation to the Industry 4.0 and digital technology vision, and as a result, they are unable to establish precise domains of action, initiatives, and projects. Novel approaches and tools to give direction and assistance to align company strategy and operations are needed to overcome rising doubt and frustration in manufacturing organizations surrounding the concept of Industry 4.0 and digital technologies (Schumacher et al., 2016).

For assessing a company for implementation of technologies, I need to evaluate the technologies of that company. Maturing technological companies improve their capabilities through time in order to attain a desired future state (Kohlegger et al., 2009). Companies must assess their existing degree of digital technology adoption in their unique environment in order to establish and manage appropriate development plans (Becker et al., 2009).

Much research has been conducted in “supply chain resilience” and “industry 4.0 and digital technologies” (Ralston & Blackhurst, 2020) and methods for quantifying the supply chain’s resilience (Pettit et al., 2019). For example, Ivanov et al. (2018) research investigates the effects of digitization and Industry 4.0 on the ripple effect in the supply chain, they mentioned their work does not claim to be comprehensive; rather, it aims to draw attention to the need for more research into the linkages between digitalization and the dangers of supply chain disruptions in terms of the ripple effect. They have recognized a few points of view that may be used to guide future study into how digital transformation impact the ripple effect and supply chain performance, their conclusions are based on subjective expert literature and practical case studies. On the other hand, Spieske and Birkel (2021) developed a thorough and mutually exclusive classification of digital technologies that support supply chain resilient. As a result, they may respond to questions while all of the technologies presented have the potential to enable supply chain resilience. They also bridged a significant research gap by examining the link between enabling technologies and supply chain resilience origins. They discovered convincing evidence that digital transformation become a vital basis for improving supply chain resilience origins, and they provide a comprehensive digital transformation and supply chain resilience architecture. This primary result is in line with prior contributions that said that the digital technology that supports supply chain is only as good as the supply chain itself. (Ivanov, 2019). In their paper, they did not explore the relation of digital technology adoption and supply chain resilience. Ralston and Blackhurst (2020) try to highlight the positives and downsides of implementation of technologies on supply chain resilience. According to the Fatorachian and Kazemi (2020) study, digital technologies could improve overall supply chain performance and lead to bettering specific supply chain operations (system elements/components).

To conclude our literature review, to the best of our knowledge, no previous research has empirically tried to find links between digital technology adoption and supply chain resilience; the study conducted by Frederico (2021) started an important debate on how Supply Chain 4.0 might work together to make supply networks more responsive and robust. In particular, the technological levers, which are truly digital technologies, were introduced and analyzed in terms of which supply chain processes they may be deployed in and what performance aspects they can enhance. In the other study, researchers aimed to clarify the function of supply chain visibility in the relationship between supply chain mapping and supply chain resilience. Their findings revealed that supply chain mapping has a significant impact on supply chain resilience. They also discovered that supply chain mapping plays a substantial mediating role in the relationship between supply chain resilience and supply chain mapping (Mubarik et al., 2021). Zouari et al. (2020) in a quantitative survey research studied the relationship of digital maturity and supply chain resilience their findings showed that there is a strong need to achieve digital maturity, which, of course, benefit in the adoption of digital supply chain technologies but has an even greater beneficial influence on supply chain resilience capabilities than the digital tools themselves.

One lesson among numerous lessons which we learn from COVID-19 pandemic is that companies must be resilient in order to keep their operation running. The extent to which a company's supply chain can adapt and alter during times of change is referred to as supply chain resilience. This notion is crucial since a company's supply chain must be resilient in order to function. A business that understands supply chain resilience can withstand the consequences of a supply chain interruption.

CHAPTER 3 METHODOLOGY

This study aims to explore the research question of whether and how the adoption of digital technologies can be a factor for building supply chain resilience. Since resilience is more easily identified during periods of crises, we used the contemporary COVID-19 pandemic crisis as an opportunity to conduct this research. In other words, we analyzed in this project the relationship between digital technology adoption and the existence of elements of resilience in the specific context of the COVID-19 pandemic crisis.

The subliminal hypothesis behind this research project is that digital technologies should improve customer experiences by giving supply-chain managers complete leverage and offering consumers greater transparency. Additionally, digital technologies should assist businesses in collecting, analyzing, integrating, and interpreting high-quality, up-to-date data. This data could be used to build automation and forecasting that will eventually replace traditional supply chain management. Finally, digital technologies should also help manufacturers to adapt to changing conditions quickly and easily, allowing for faster recovery and the creation of a resilient supply chain. Because of their capacity to rapidly process information inside the organization and its supply chain, digital technologies are directly tied to organization resilience.

For achieving the ultimate goal of this research (i.e. to understand the relationship between digital technology adoption and resilience), after conducting a literature review, a qualitative case study was conducted. According to Mitchell (1983), a case study is a “detailed examination of an event (or series of related events) which the analyst believes exhibits (or exhibits) the operation of some identified general theoretical principles” (p. 192). An alternative definition is proposed by Yin (1994), who states that a case study as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident” (p.13). Still according to Yin (1994), a case study uses multiple sources of evidence, which are triangulated to deepen our understanding of a contemporary phenomenon. Case studies are excellent for theory building, providing detailed explanations of ‘best practices’, and providing more understanding of data gathered. Yin (2017) emphasizes the process: the approach has been closely watched, and the result is likely to be the production of a high-quality case study. The case study is defined as an empirical investigation into a current phenomenon (the 'case') in depth and within its real-world setting, Yin (2017) emphasizes the power of high-quality case study research that focuses on validity, and reliability. A case, like one experiment, is suitable when that case represents a critical case to test a well-formulated theory, an extreme or unique case, or a case that reveals a previously inaccessible phenomenon. Yin's (2017) recommendation for case study research protocol should include vital research issues, the design of the research, the proposed method, and the interview guide. Case studies are also complicated and present unique challenges to the researcher in terms of providing an explanation that described events.

Particular for this research project, the case study was performed in the following five steps:

- Literature review
- Determine initial research questions
- Data collection (Case studies selection - Interviews – Transcription - Theoretical sampling)
- Data analysis coding and validation
- Data classification

After a literature review regarding the field of supply chain resilience and digital technologies, the researcher tried to identify key concepts related to elements of supply chain resilience and, digital technology adoption trends, which leads to the formulation of the initial research questions.

Afterwards an explorative and qualitative study is conducted through open and semi-structured interviews, which used a guide (presented in Appendix B) to help the researcher to collect information about how the companies within the supply chain under analysis have adapted to the pandemic and what roles digital technologies played to that effect. Indirectly, the interview also allows the researcher to have an idea of the resilience elements in place and the company's maturity with respect to digital technology adoption. The data collected during interviews is transcribed and then analyzed using content analysis techniques to find patterns in the discourse of respondents.

For the content analysis, the researcher needs a couple of ‘lenses’ to interpret and analyze the responses from the interviewees. These ‘lenses’ consist of two codebooks, which were built from the literature review conducted in the previous step. One of the codebooks is about ‘digital technologies’, so to allow us to understand which, how and why digital technologies were adopted by the company. The second codebook is about the elements of resilience. Codes can be sorted into higher-level ideas and then into categories as additional data is collected and examined. The transcription of the interviews is then ‘tagged’ according to these two codebooks, and it is based on this tagging that data analysis is performed, and which bases the findings and propositions that derive from this research. The codebooks produced in this research are presented in Appendix D.

3.1 Data collection approach

Data collection for this study is based on interviews based on a semi-structured interview guide, which is the most common style of interview done during a questionnaire interview to acquire descriptive information. A formal questionnaire comprised of open-ended questions, a questionnaire aimed to 'get the facts', was employed.

In this research, three companies' administrators participated in one-hour interviews. Most of the data collected results from the interviews, however, we also collected some public information about the companies and about the supply chain in general, mostly from the website of the companies and other websites that officially publish some information about those companies. The sampling technique employed is the so-called purposive sampling, which is a type of non-probability sampling in which researchers use their own judgment in selecting samples of the population to participate in their surveys and in our case the right person for interviewing (Palinkas et al., 2013). Data collection should continue until data saturation is reached, which is the condition in which no new information is aggregated with new respondents (Chun Tie, Y et al., 2019). Unfortunately, we were not able to reach data saturation in this research, for reasons beyond our control. In spite of that (which is a limitation of this research), some meaningful relations were found, which justifies this project.

According to the case study theory, the research team selects people and data sources with the goal of addressing the study question. Case study technique begins with the collection of initial data and continues throughout the study period. Incidents are noticed and tagged in the data. As the research team reviews the data acquired from cases, ideas or concepts emerge (Yin, 2017). In addition, abduction, defined as a form of reasoning that begins with examining the data and forming several hypotheses that are then proved or disproved during the process of analysis, aids inductive conceptualization (Birks & Mills, 2015). Theoretical sampling coupled with constant comparative analysis raises the conceptual levels of data analysis and directs ongoing data collection or generation (Birks & Mills, 2015).

The steps to the case study theory in this research are; first researcher contact with individuals from the strategic level CEOs, managers, and interview with them in the second level researcher could interview with supply chain partners – at least one from upstream and downstream of the supply chain to collect information about the involvement of companies. After collecting preliminary data is transcribed from interviews, the researcher could be able to data analysis in the next step.

3.2 Data Analysis

The data from the case studies were analyzed in several ways, as prescribed in case study research. Due to the data complexity, the data analysis process is an iterative one. The analysis begins simultaneously with gathering the data and continues throughout the data collection process and beyond. The initial stage of analysis compares incident to incident in each code. Codes are then collapsed into categories. This process means the researcher compares incidents in a category with previous incidents in both the same and dissimilar categories. Future codes are compared, and categories are compared with other categories. New data is then compared with data obtained earlier during the analysis phases. This iterative process involves inductive and deductive thinking. Inductive, deductive, and abductive reasoning can also be used in data analysis (Chun Tie, Y et al., 2019). Constant comparative analysis generates more abstract concepts and theories increasingly through inductive processes. Data analysis includes search codes based on literature review, content analysis of the interviews, cross-case analysis, and comparative analysis to identify the core categories. Finally, clustered concepts determining the relationship between those groups. It is used to reveal linkages and grouping and then try to find the relation of those groups.

In the first stage of analysis, events in each code which are extracted in the previous step are compared. The original codes which are extracted from literature review then codes compared to other codes, and they are classified into groups depending on prior processes. The study anticipated codes that were listed in the code book, and then researchers classified them into two essential groups, namely digital technologies, and elements of resilience. This technique involves our research team comparing incidents within a category to previous cases within the same and separate categories. Future codes were contrasted with existing codes, and categories were contrasted with one another. The newly collected data was then compared to data collected earlier in the analytical processes for each case selected codes analysis because their organizational differences are indicated in matrix coding for the firm. The purpose is to uncover links between aspects in categories and find the relations.

In qualitative research, validity refers to the "appropriateness" of the instruments, methods, and data. Whether the research question is valid for the desired outcome, whether the methodology chosen is appropriate for answering the research question, whether the design is appropriate for the methodology, whether the sampling and data analysis are appropriate, and whether the results and conclusions are valid for the sample and context. Data validity includes external and internal validity (Leung, 2015).

External validity reflects how accurately the results stand for the phenomenon studied, setting up generalizability of results. To the generalizability of results, it is essential to choose multiple case studies. Our cases are Canadian and specifically in Quebec in different industrial sectors and multiple sizes, mostly small to medium, which transformed digital technologies in distinct levels of technological adoption and finally, their supply chains disrupted by the COVID-19 outbreak. External validity reflects how accurately the results are the phenomenon studied, proving generalizability of results; in the following section, I present all the steps for data validation to data classification (Whittemore et al., 2001). Besides the external validity, one should also take into consideration the internal validity of data, which consists of a reliable cause-and-effect link among data. The final issue in research design quality, internal validity, is only a concern in explanatory case studies, where the researcher is trying to prove that some outcome was caused by an independent variable. In this research, since the three companies identified as a case for complete supply chain the internal data validation is done between companies (Whittemore et al., 2001). For external validity, the research result of the companies compares with the other companies out of the chain. In this study, the software Nvivo was used to that effect, since it can distinguish the interview environment depending on the coding and definitions. The NVivo software was used for data analysis, and the content analysis methods were followed. All transcripts, as well as the Element of Resilience and Elements of Technologies codes first mentioned in the text, were entered into the program for identification. By comparing incidents to incidents, labelling first trends, and beginning to look for code similarities, initial coding categorizes and adds meaning to the data. In the following step of the process, I attempt to find a core category, theoretical data saturation, constant comparative analysis, and finally in the final stage advanced coding is required to create a theory that is data-driven and has explanatory power, which means the integration of the previous steps to explore the meaning of the category's relation in the next part the data analysis detail present.

3.3 Data Classification

In classifying the findings in the studies, I read, I sought to distinguish between abstraction of analysis and interpretation of data discernible in the findings from the abstraction of the phenomena, events, or cases that constituted the subjects/objects of analysis and interpretation. In open coding, I use an interview; this type of finding was characterized by emphasizing nominal or categorical data, lists and inventories of topics covered by research participants in interviews and focus groups.

The thematic interview method is a finding that reflects a greater degree of data transformation. More accurate to the interpretive meaning of the theme, thematic method conveys an underlying or more latent pattern or repetition discerned in the data. These reports revealed more of a discernible effort to move away from merely listing topics toward describing themes (or the patterned responses researchers discerned from the topics).

A thematic interview is a form of qualitative research, but it is a form at the lowest level of abstraction. In the next phase for classifying the empirical data Conceptual/Thematic Description (selective coding) is defined.

I distinguish between the nominal usage of ideas or themes, in which they are just utilized to label and organize parts of data, and the actual application of concepts or themes. The interpretative use of concepts or themes, in which concepts or themes are employed conceptually or thematically to reimagine dates.

Such presentations are useful not just for grouping data, but also for expanding the theoretical or other intellectual tradition from which they were imported and/or illuminating an experience. When ideas or themes function as a labelling or presenting strategy rather than an interpretative one, conceptual/thematic descriptions border on thematic interviews. Furthermore, I arrive at the final level, Interpretive Explanation, which fully incorporates explanations of a phenomenon, event, or case.

Case study research has several advantages. The ability to distinguish a link between events, setting, and individuals is one of the benefits of case study research. The ability to acquire data in a variety of ways. Capability to capture participants' context and experienced reality. Capability to investigate deeper reasons of occurrences. Case study research is extremely flexible to the researcher's demands and the purpose of the research issue.

Our case study objective is to do extensive research on a specific case in order to discover critical factors, processes, and relationships.

CHAPTER 4 RESULTS

4.1 Description of the studied supply chain

This research focuses on three companies in Quebec embedded in a single supply chain, which is analyzed through one case study. Company A is the top element in this supply chain as the leader for receiving raw material to sell the product and identified as a product branding company. Company B is the logistics operator that distributes the product, while Company C is the basic material provider known as manufacturer. The supply chain of this case study is illustrated in Fig 4-1, which is going to be explained in the following subsections. The three companies that participated in this research project are highlighted in orange in the figure. There are a couple of companies in a complete supply chain which provide raw material and in the other hand those companies which sell the product to customers, those companies which interactively connect to the logistics operator, and retailer company connected to company A. Furthermore, company A perform direct sales to the final customer via online platforms. In fact, company A plays the role of the orchestrator of the value chain.

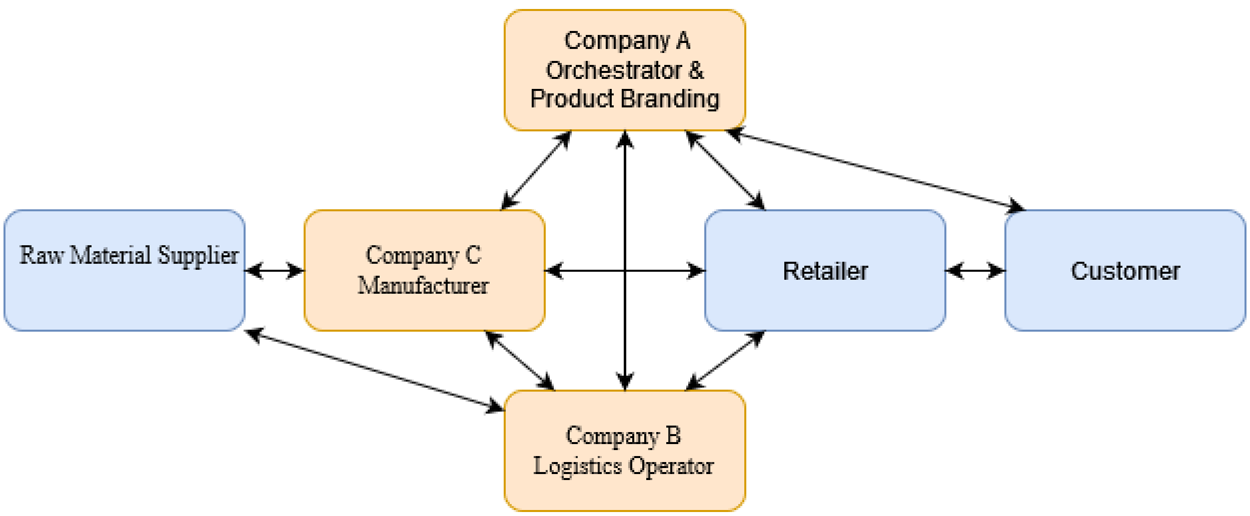

Figure 4-1 Supply chain arrangement

Company C receive the raw material from the raw material supplier, whose shipping and logistics are handled by Company B; Company A receives the product from Company C through Company B, makes modifications and packs it before handling it to the retailer (always with the assistance of Company B); Alternatively, Company A can also sell directly to the final customer through an e-commerce platform. In sum, Company A plays an important role for organizing the value chain from the raw material to the final customer.

4.2 Company A (Orchestrator and Product Branding)

Company A, a Montreal-based company recognized for producing pet food with a low environmental impact, they are introducing pet food using new types of proteins created from alternative sources, such as insects. Also included are vegan proteins, as well as recycled materials such as pulp from a juice firm. The company's entire aim and differentiating element is employing innovative proteins that have a greater influence on the earth, such as consuming fewer resources or being incorporated into a circular economy, as well as having positive effects for dogs. This new product not only provides an innovation that is wonderful for pet health, but it also helps to safeguard the local lakes and rivers. As fish continue to migrate to and overrun Quebec waterways, the Montreal firm is collaborating with an American company to add a type of fish into its original formula. By advancing this knowledge, the firm aspires to become a Canadian leader in the battle against these noxious fish that endanger indigenous species and their environment.

This revolutionary product is currently available in the great part of Quebec and most pet supply retailers in the Province. They have roughly 15 SKUs that are distributed in over 500 retailers in Canada and South Korea. They also sell online on Amazon and on their website, with e-commerce accounting for a sizeable portion of their revenues. Their organizational structure includes three co-founders. A CEO, a Chief Innovation Officer, and a Chief Marketing Officer are all part of the team. And beneath each of them are some employees and colleagues and the logistics department are located beneath the CIO. The corporation employs an accountant and in total more than ten people work in this company. Therefore, someone oversees all the invoicing, accounts receivable, accounts payable, and marketing and social media, and they have someone else in Toronto who is an expert in digital marketing. They have a traditional structure from the top down, but it is pretty flat architecture on a daily basis.

They had to create a lot of internal tools and processes to have their staff handle those e-commerce shipments when the pandemic affected their sale and distribution approach. The other changes were the process transformation, where it was primarily done manually, for example, utilizing excel sheets to store all their stock data and compute manually to transfer all the invoicing, all of the stocks, and all of the POs into one integrated system which called ERP and in their case cloud-based ERP. It was the most significant shift following the pandemic, and what enabled the ERP system to link to a Shopify site that tracks sales and is also linked to their inventories, allowing them to access data.

They employ shipping technology that integrates with other online networks. They were utilizing it before the pandemic, but not all of its functionality since they had basic needs considerably before the pandemic and the volumes that they had. After the pandemic they added several new features, such as the ability to filter items based on their weight or geography. They become much more exact in applying the appropriate shipping fee based on the order's location. They also improved several procedures related to the creation of shipping labels. The important thing that happened with COVID-19 was that their sales increased, specifically in Asia. The company managers believe that the reason for this growth was more people during the pandemic stay at their homes and they have more time for having a pet. There are also new opportunities which have resulted in their revenue increasing. This revenue improves their robustness in various aspects. It strengthened and automated them not just in logistics, but also in marketing, branding, and even accounting. As a result, COVID-19 had a noteworthy influence on process optimization and formalization since they apply more automated tools. Since the number of orders increased and they should more manufacturing and that means they need more ingredients, and that increased complexity, therefore they determined that product quality assurance, as well as quality assurance management, would be integrated into their internal operations rather than relying solely on their supplier side. For sales prediction they applied an algorithm which models the sales based on past data and they must implement an optimized machine learning sales forecasting models in their sales department. Furthermore they have a proactive algorithm for improving their robustness which put the order in advance based on the market and customer analyses, it means they want to transit from reactive supply chain to proactive one mean, while ERP system enables them to process more data in a limited time, whereas it integrates the invoices the stocks for instance when they receive an invoice from a customer, the person who is working in logistics now knows immediately that the stock will go down by that amount and the quantity of stock will be updated. Following the COVD-19 pandemic, they have a decent forecasting system in place, as well as enough stock levels, however, they face significant unpredictability in terms of production. Their long-term plan is to find a more resilient supplier partner. They are evaluating new partners as well as alternative ones for expanding their supply chain network and collaboration. According to their estimate, they will be back on track within the next six months. They employ artificial intelligence (AI) capabilities in their shipping to automatically track every shipment that a producer sends to a consumer via e-commerce, and it reports on any shipments that arrive late. As a result, they have a guarantee for their shipments accordingly if they are dispatched late, the courier company is obliged to ship it within two days. That platform might assist them in making an automated claim, which courier does. As a result, they would be able to recoup hundreds of dollars each year as a result of that digital tool. In order to improve their shipping capabilities and automate with integrated systems, they use a bar coding machine for tracking their packages. Meanwhile they have access to their inventory, and they have an update report instantly.

For supply chain performance assessment, they define numerous KPIs which checks and updates on time schedule they mostly focused on e-commerce and customer fulfilment precision since their company is customer centric based on their mission, they try to decrease the time of order placement to delivery time is crucial for this type of company. They have distinct KPIs for e-commerce, distributors, and export. For example, in transportation, they want to spend no more than 10% or 15% of the order on transportation. Therefore, transportation is a sizeable portion of their costs. Then there's stock turnover, which is another KPI where they do not want to have too many stocks in their warehouse since it is costly. They have particular ratios and KPIs they wish to achieve with their stock. E-commerce plays an important role for this company since most of the customers prefer to order online accordingly e-commerce KPIs monitor and revise for improving productivity and customer satisfaction. They alternate the producers in order to improve their robustness.

According to the technologies that company A applied, this company is in the middle level of developed digital technologies one of the most digital technologies that they implement in their company is ERP and this system connects to the online sales platform and shipping platform and those interchanging data enable them to be more visible and transparent in the future they can enable the advance feature of ERP system which made it smarter and empower with analytical tools. The result of company A content analysis depicts Fig 4-2, which shows the number of references of the coding in the interview. In Fig 4-2, the percentages of each cited code is compared. It demonstrates that visibility with 45% code coverage which is the ability to detect threats and events that might effect on the supply chain's performance and it needs the information from the supply chain from bottom to top for improving the quality of visibility and it is one of the resilience elements, agility and flexibility are the second and third most cited codes and there are important because the digital technologies in this company able to exchange data with the other companies which are members of the supply chain and this exchange make a company more agile with the prediction and more flexible with adapt to changing conditions with real-time information . ERP is one of the technological elements that covers 35 percent of the interview ERP is an integrated management system that manages critical company processes in real time using software and technology codes and is ranked fourth. The least codes are machine autonomy, which is a component of technology and less applied in this company.

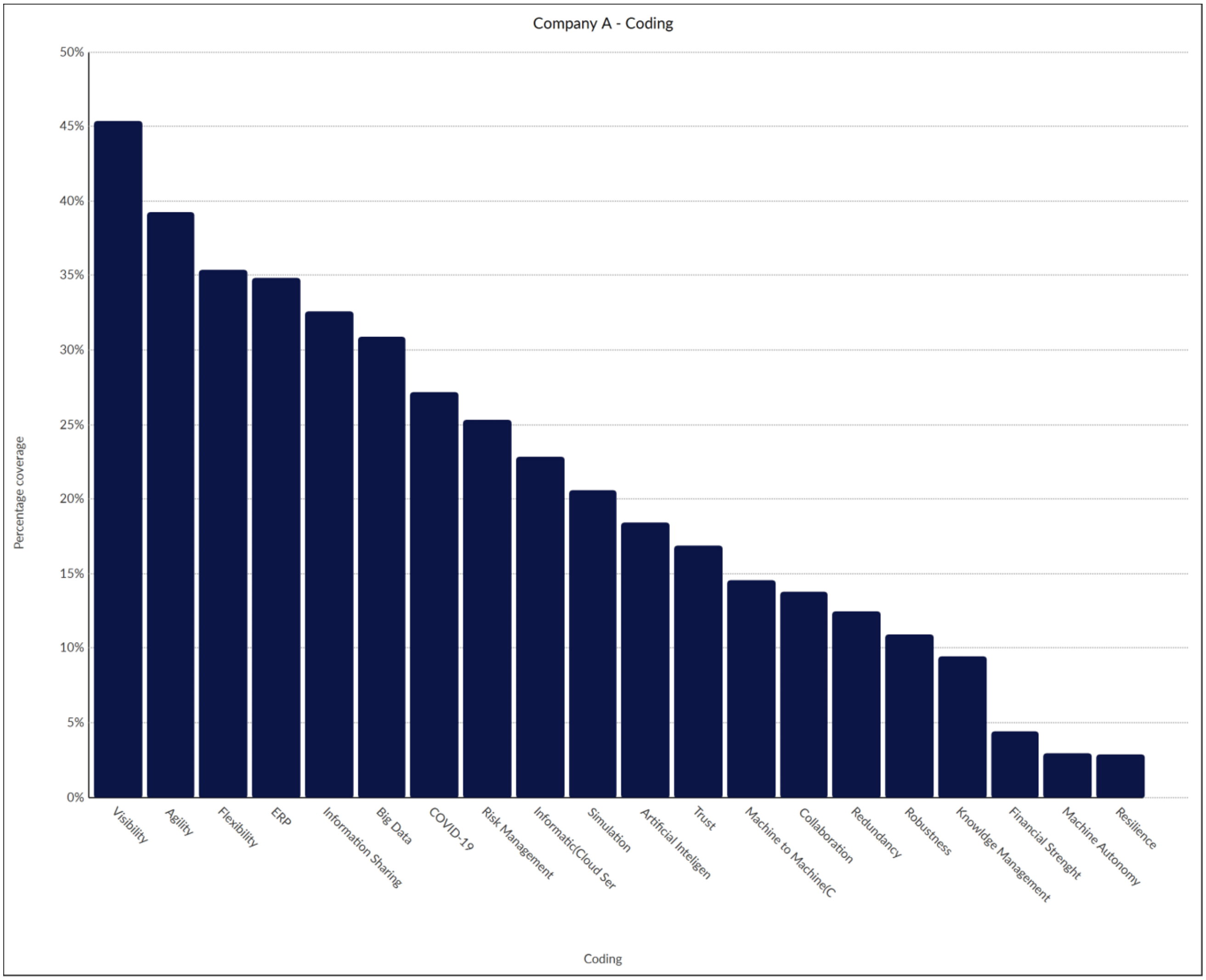

Figure 4-2 Company A Coding coverage

4.3 Company B (Logistics)

Company B is a logistic company which provides third party logistic services for company A, and it is a part of supply chain that I will analyze. Company B was established about 20 years ago, which is a hybrid carrier that combines premium truckload and less-than-truckload services provided by its fleet with a world-class network of third-party logistics partners seventy people work in this company. They deliver dry van and refrigerated freight between Canada and the United States in a timely manner. The companies' workforce is made up of highly qualified transportation specialists working in a cuttingedge technological environment. Their fleet is one of the safest on the road, transporting the cross-border cargo in clean, cool trailers operated by well-trained drivers in current late-model trucks. They have access to a large network of carriers, and they have their own method of screening them to ensure their dependability. They face fewer problems because everything is done over a distance, and they have their own technology for screening carriers. For each customer order, they create a unique quote and give it to the consumer through email. After accepting the order, they entered it into their transportation management system and then followed up on the order, the order schedule, and provided updates to the customer. Most third-party logistics companies have a sales department that obtains requests, and then, once their requests have been received, they will contact the operations department, which performs a market analysis and choose the best carrier for this purpose.

In the technology sector they have an integrated system that includes most departments, such as Sales Management and Transportation Management System, which is a cloud-based ERP system. It is designed for transportation management systems, and it is optimized for logistics organizations or carriers, allowing them to have a comprehensive picture of all transportation orders. It enables the entry of data for bookings, tracings, and tracking, and the third component of that technical system is the accounting part invoicing the transportation management system is the most significant component of this technological tool for them. This technology plays an important role as a data search tool. It allows companies to track prior orders and make predictions about their present and future market based on the past. Their customers could check the tracings that company B has entered into their transportation management system. They could create any type of report they want with the data in the system and export it to an Excel file to do anything they want with it. Their customer summary sales per month is a report that they commonly employ. One feature of the software that they frequently utilize is the ability to customize reports they measure the performance month by month, and they analyze their historical data to compare their revenue and profit which showed their performance it means check their KPIs and the best assessment is to compare the month with the same month in the last year since this kind of business is seasonal and depends on the weather conditions. To manage their warehouse and update the quantity, they have their scanning code system which is not RFID-based, but it is nevertheless a digital tool for controlling the flow of the warehouse, they label each sort of item with a unique scan code, allowing them to manage inventory and keep track of everything that is received and shipped out accordingly this system enable them to have an online inventory management.

After COVID-19 pandemic the only thing that has changed is their shipping cost, which has decreased due to factories shutting down during COVID-19. When manufacturers went out of business, their numbers plummeted dramatically. Everything, including revenue and profit, has decreased and they have lost some of their clients. In the other hand because of the government compensation program and the time that families spent in their home in the pandemic period the customer had more on daily expenses in comparison with before the pandemic. After the pandemic, the cost of container shipping from Asia to America increased three times, which means the market is not stable yet. According to the technologies used by firm B, this company is in the entry to middle level of implementing recent technologies.

For data analysis, we used some content analysis tools available on NVivo. The result of company B content analysis depicted in Fig 4-3 shows the number of references of the coding in the interview. In the Fig 4-3, the percentages of each cited code indicates that Covid-19 is the most cited subject in the interview, with 25% of the percentage coverage. The reason for that is the condition that company had to cope with during the pandemic, and the learning curve from the supply chain challenges that this pandemic crisis brought, which was only possible because of the sharing of information among peers (the second most frequent code in the analysis), which is an element of resilience and important for each company for being more transparent. Another important element was their ERP system, with 20% coverage the interview data analysis, a technological element which enabled the company to exchange data within and out of the organizational chart. Next, "visibility" shows up as the second most important resilience code in the sample, which adds up to around 19% of the interview codes..

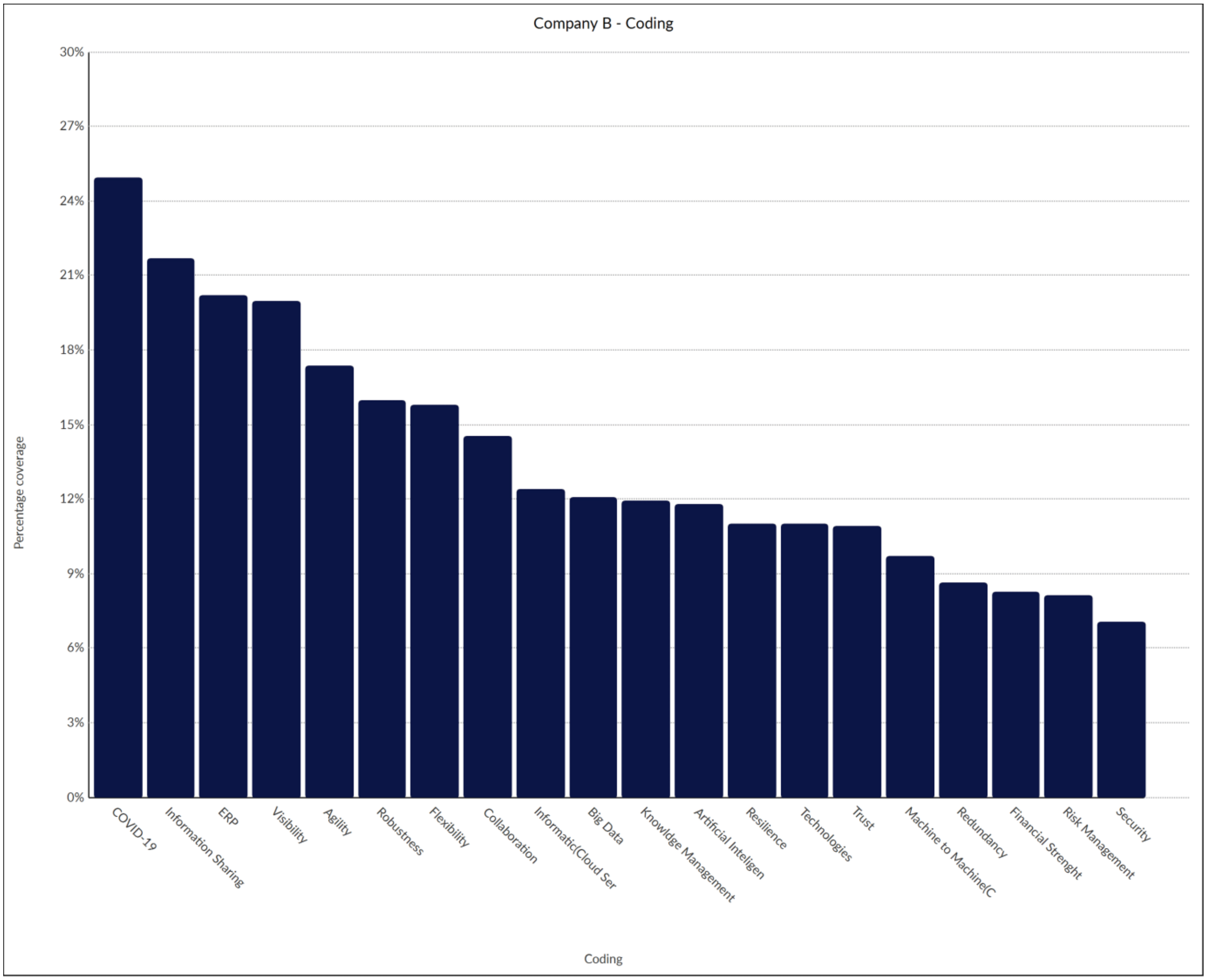

Figure 4-3 Company B Coding coverage

4.4 Company C (Manufacturer)

Company C is a pet food manufacturer. Since their family company was established more than 50 years ago, the firm has evolved to become the world's biggest privately company, multinational pet product producer and distributor. More than 270 employees work in this company in Quebec.

The firm is committed to developing practical and creative products that improve the health and well-being of pets across the world. Their animal and customer research networks make sure of their product quality. They monitor customer demands and trends in order to be ready with the latest items when those needs change and investigate and invent efficient methods of producing products in order to enhance performance, cut costs, and increase sustainability.

They produce 2000 tons of material each year and because of the quantity of production they rely on other producers for their raw material in the supply chain.

After COVID-19 pandemic, it has become harder to supply raw material, they have plans to diversify their sources, which means increase their collaboration, however, finding new producers is challenging since all materials and processes should have the same quality. Until the moment when this thesis was written, they did not manage to get back to the situation they had before the pandemic. On the other hand, their sales had a positive impact on their revenue, despite the slowdown in shipping lines and the surge of shipping costs since the demand from people who stay at their home increase. Because of the complexity of their product which has expiry date they reassess their supply chain for adapting to new circumstances one thing they learn is keep their supplier as short as possible in distance. The digitization of the data that they are going through is mostly beneficial to the process and it facilitates the processes. They do anticipate that things will slow down soon since people will have other things to spend their money on besides pets nevertheless, they monitor the market on the seasonal period. They rely on ERP for their PO's which automate the procedure and they have a plan to transit to cloud based system this new system will enable the company to automate the import and export material since some of the material requires to obtain permission for import/export and this procedure is also time-consuming and manually basis. On the other hand, they believe that implementing modern technologies is costly and it takes time to adapt to those in their company. Their priority after pandemic recession is to find material and expand their supplier sources and then they will plan to automate the process with digital technologies. They are continually looking at automating as much as feasible, based on the selling material and how they work. So, when they have a new line, a new product, it is normally quite manual, and then they will look at how the market reacts to it, and then they will automate increasingly. Company C, based on the technologies it employs, is at the early stage of implementing recent technologies. NVivo content analysis tools were once again used to process the information from this interview. All transcripts, as well as the previously described Element of Resilience and Elements of Technologies codes, were entered into the computer to be identified. In Fig 4-4, the percentage of each cited code shows that the Covid-19 is once again the most important code that was cited in the interview with 28% of the percentage coverage since it is the most challenging topic for most of the companies and Company C as well, followed by resilience with 20%, which is a resilience element in the supply chain and it shows that improving the resilient is an important subject for Company's administrations, and technologies is one of the topics that play a role in conversation since the company did not implement advanced modern technologies therefore technologies is important to discuss, Agility is important for Company C and this code stand in the fourth place with 10% based it is because during the pandemic their supply chain was under pressure and they want to improve their inventory of their company. ERP has the minimal coverage since the ERP was implemented recently in their company and before that they did not share the data in their company.

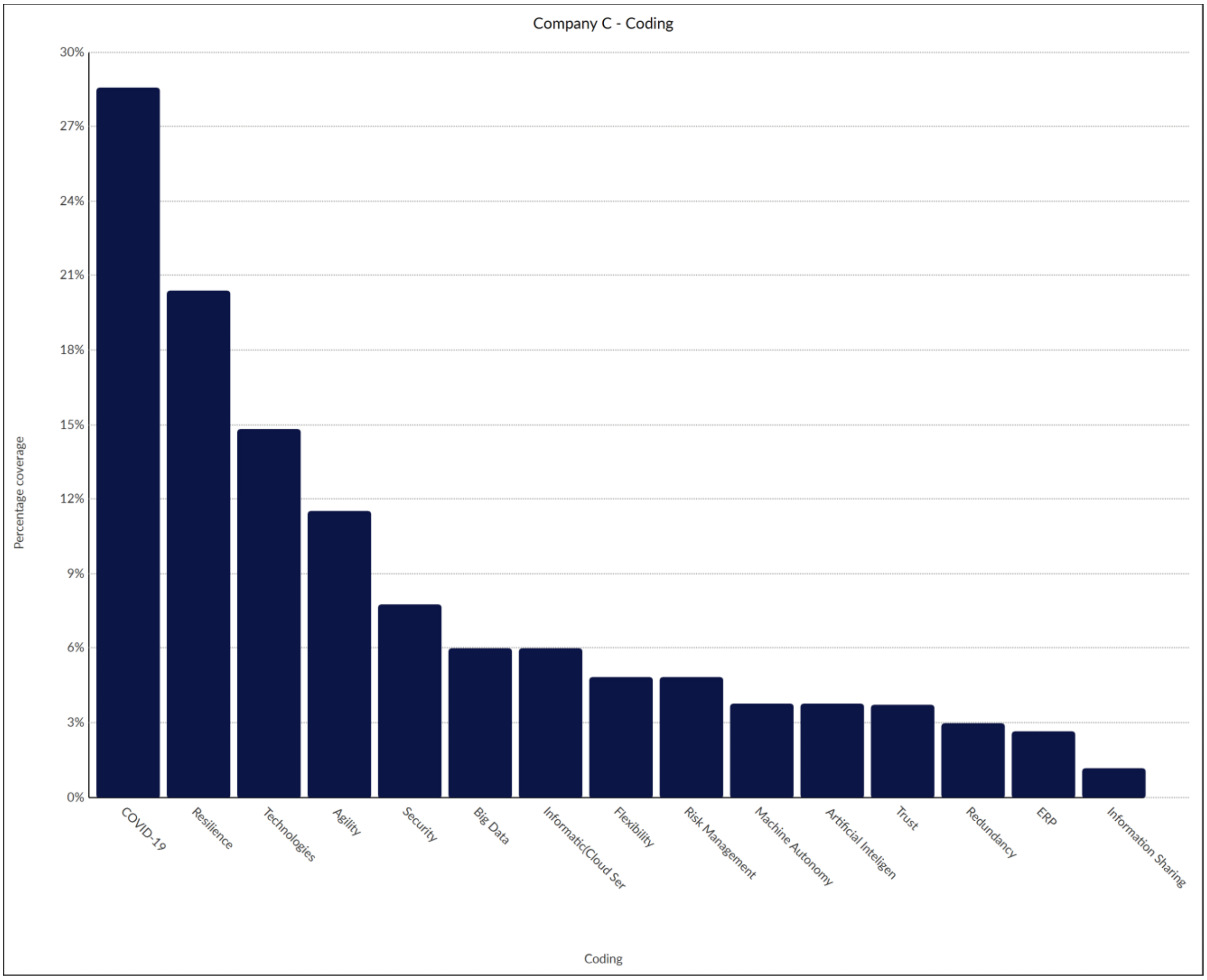

Figure 4-4 Company C Coding coverage

CHAPTER 5 ANALYSIS AND DISCUSSION

In accordance with case study best practices, the research team selected participants and data sources in one only geographical location to control for business environment variance, and a comparative analysis with the three companies was performed through the coding and categorization of the interview transcripts. In the first round of analysis, we compared incidents in each code. Then, the initial codes are compared to other codes, and they are then grouped into groups based according to previous steps I expected codes which mentioned in code book Appendix D and then I grouped them into two important groups namely elements of digital technologies and elements of resilience which include their own codes. This procedure entails our research team comparing incidences within a category to earlier instances within the same and distinct categories. Future codes were compared to existing codes, and categories were compared to other categories. The collected data compared to data gathered previously in the analytical steps for each case selected codes analyze since their organizational are different those different shown in matrix coding for company A (Fig 5-1), Company B (Fig 5-2), Company C (Fig 5-3). The Nvivo software can aggregate and discriminate the interview context based on the coding and their definitions.

A case study theory research's finding is communicated as a series of groups that are related to one another in an integrated whole and stated in the construction of a theoretical approach. According to the case-study procedure, and based on our data analysis, I noticed that firms are well structured in terms of their functions and their responsibilities, and changes and market uncertainty do not have an immediate major impact on them during a pandemic. I removed those technologies with zero count from the query matrix, such as Augmented Reality and Additive Manufacturing. Matrix coding query for Company A is illustrated in Fig 5.1. This figure shows the relation between digital technologies and elements of resilience based on this analysis four technologies namely ERP, Big Data, and Information (Cloud ERP Services) and Artificial Intelligence have an important role to improve the resilience in the supply chain via sharing ERP data with suppliers they can deal with unpredictability. All the companies which are studied as a case in this research uses cloud ERP to create a circular supply chain that combines and executes operations by collaborating with each connected department. Cloud ERP enables companies to link disparate systems, unify data warehouses, and speed the development and implementation of new services - all of which are crucial in unpredictable times. They make a gateway via which their customers can quickly check demand on their goods. They can also connect with their suppliers via an extranet. Because they can adapt their own capabilities in response to changes in their

ERP, they can correct an imbalance before their customers react and require a change. Their vendors can offer them real-time feedback on the progress of their replenishment requests. If they are aware of a problem with their material supply or capability, they may assist them or discover an alternate provider by arranging with the ERP system. This input can be routed over the same extranet infrastructure that connects their ERP systems and generates data which is used in big data analysis. Aside from the suppliers, Company A improves its resilience to unpredictable events such as pandemics and other third parties' sudden changes in the supply chain. If the ship departs without their goods, the ERP linkers can assist them in requesting a new shipping option well in advance of the day they expected a delivery's well. The second provider may be a bit more expensive, but it may rescue them if the first supply is unable to satisfy their demand. Another tried-and-true option is safety stock. Safety stock acts as a buffer against unpredictable supply, and that resilience is right in their own stockroom, made possible by data collected using ERP systems and AI solutions that can help companies automate and optimize proactively not only reactively, furthermore, intelligent ERP systems have advanced supply chain planning technology that suggests lead-time modifications dynamically based on real vendor performance and improve the effective level of redundancy with providing an accurate level of product and inventory and predict the demand in supply chain that real-time information improves the real-time assessment of capability of the supply chain ERP as a real-time analytics and decision support tool, as well as electronic data interchange systems like those used by Shopify which is an online shop like Amazon, may assist in providing baseline data, which in turn supports investments in spending, suppliers, and commodity analysis. Together, these provide enriched data sets that can assist company managers in better understanding the dynamics of the procurement process; making decisions related to customer needs, production schedules, logistics and delivery requirements; anticipating upcoming challenges, including shortages; and responding quickly to market shifts which means more make an agile supply chain, furthermore, those data make company more transparent which is equal to visibility. Machine to Machine (M2M) is a term that is used to describe technologies that allow networked devices to share information and conduct activities without the need for human intervention. This information sharing enables supply chain to transfer data without any intervention and enables the decision maker to have a wider view of their supply chain as a whole. Artificial intelligence and machine learning facilitate system communication, allowing them to make their own independent decisions such as those data gathered from online platforms AI-powered systems employ techniques for learning from cognitive data.

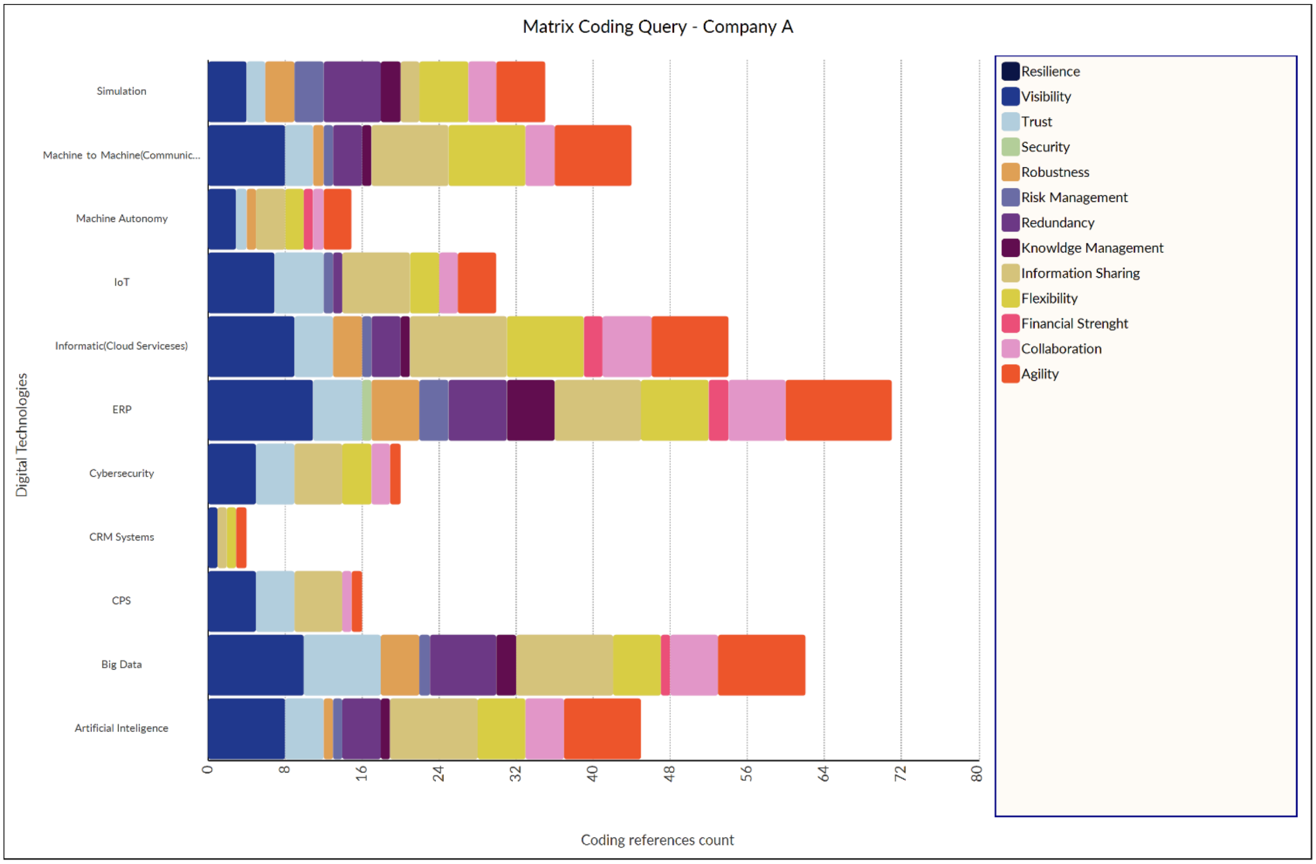

Figure 5-1 Company A matrix coding

Company B data analysis shows that big data from digital technology make an important role in their supply chain resilience since the company has a long history in the logistic service sector, they can enhance demand management with data that recorded historically. ERP also helps in this situation. Use the data gathered from each previous client in order to create better and better forecasting tools. Request that their customers supply and extranet to connect ERP systems upstream as well. The difference between company A and B is that company A share their ERP platform with their customers, in other words, they open the gate for data transfer while company B use ERP data internally accordingly since company A is fractionally brand new, they can access more data by sharing with other companies while company B has their own saved database. In company B big data has the most relation on the supply chain resilience elements, this company has access to data from across their sector, which may lead to increased knowledge and collaboration, resulting in enhanced operational efficiency and customer service. ERP transaction data, demand projections, consumer location, bar-code system reports, and other data solutions are examples of structured and unstructured data. This allows Company B to generate perfectly accurate conclusions that influence their business choices and supply chain applications. Big Data allows Company B to improve inventory management systems and decrease inventory write-downs. A business's inventory is at the core of the supply chain, and without precise and adequate data, managing it properly may be challenging, resulting in resources waste and disgruntled customers. Big data accelerates inventory turnover, provides a consistent time to delivery, expands shipping options, and reduces back orders and other consumer irritation areas. This is because they have data to more correctly forecast inventory movement and manage inventory levels proactively rather than responding to a change after it occurs. For both companies, big data increases trust between the consumer and companies are in contact with each other and they are aware of the status of their order and changes in order resources can be observed by the customer. Company B gathers a variety of data, such as package size and weight, destination, current position of cargo, and so on. However, they frequently struggle to derive valuable insights from such data. This approach has gotten simpler and error-free as a result of Big Data Analytics. Machine-to-machine telemetry is all about making assets, goods, and shipments "visible, smart, and connected," producing real data that can be utilized in several ways. By outfitting containers, equipment, and cargo with automated locating and sensing technologies, companies could achieve real-time visibility and control over complicated containers supply chain activities. M2M is the process by which one machine communicates with another over a communication link. Company B is more rely on the human forces and the regulation which impose during a pandemic between the US and Canada accordingly the topic of Covid-19 is more important for them, furthermore, since the ERP system of this company is not advancing as the Company A. ERP is not the most technological aspect of this company but data still make an important role and it illustration shows a high level of feature dependency of Big Data and other elements of resilient in addition in this company the level of machine to machine communication is higher than other companies since they should track and trace their cargoes and those info collect and share without human intervention.

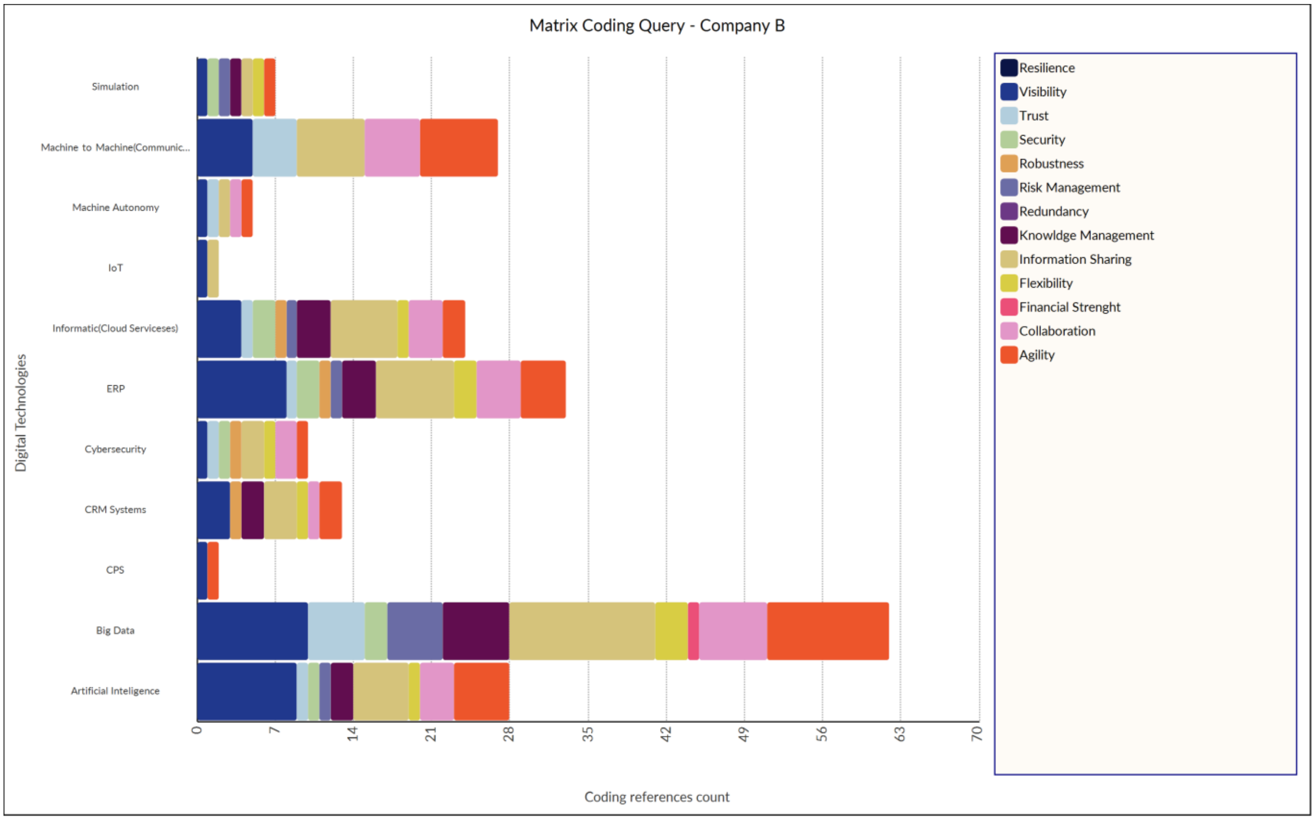

Figure 5-2 Company B Matrix coding

Company C implement their cloud-based ERP system recently since the ERP is a modern technology in their company it takes a time to fully integrated to all departments and communicate with them therefore there is a lower level of dependency between since Company C establish a single view from organizational data and suppliers by bringing data from all stages of the supply chain to a single dashboard. A modern cloud ERP system could connect to the other machines in the factory and assist them in providing real-time data across the logistics and inventory, resulting in improved data-driven business choices and the resolution of demand and supply mismatches which made them more flexible, agile, and more visible for risk management. ERP system able to generate of data flow which is named as Big Data this Big Data would analyze with AI tools and predictive models can learn from historical data for future events. The result of company C in comparison with company A & B shows that the Machine Autonomy important for this company since they are manufacturers, since they suffer from restriction of pandemic risk management is important to control future disturbance.

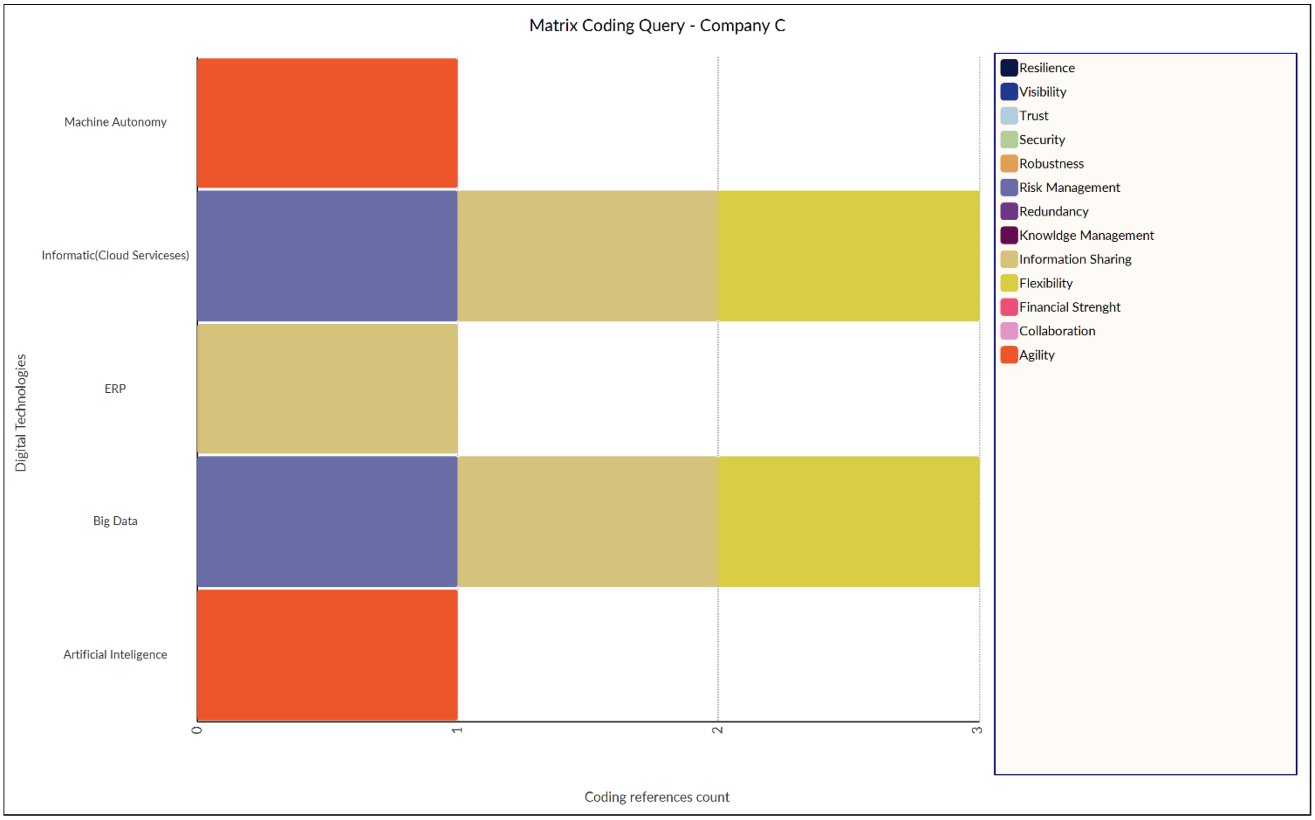

Figure 5-3 Company C Matrix coding

Forecasting demand is crucial to supply chain resilience. And it all begins with having comprehensive visibility over your whole organization. Integrating data streams is the first step toward enhancing the supply network since it allows organizations to make informed decisions. They may, for example, seek to alter inventory holding duration for essential aspects in order to prevent being caught off guard by a sudden rise in demand. Data analysis shows that connectivity that generates data would make the supply chain visible and transparent. Visibility is widely acknowledged as a vital component of the supply chain's performance. It is based on analytics; it necessitates the use of technology that can collect and transmit real-time data that translates into actionable insights. The digital economy of today necessitates a new strategy to managing the whole supply chain ecosystem, one that makes use of the cloud, real-time connectivity, and advanced analytics. This is where a fully integrated set of planning, sourcing, coordination, and logistics platforms powered by big data analytics and artificial intelligence can provide improved visibility, recommended actions, and predictive risk mitigation for supply chain resiliency. Analytics can assist executives in identifying threats and variations in demand and responding effectively to them. In other words, it may be a valuable tool in a company's supply chain resilience, which many executives recognized but did not use prior to the pandemic.

In the last step of analysis, the data of the three companies analyzed together for achieving this purpose all the data from interview collected and then a query run on the whole passage same as previous steps all the words and concepts tagged and analyze in one file. Figure 5-4 demonstrate all company's matrix query and show the relation of digital technologies against elements of resilience.

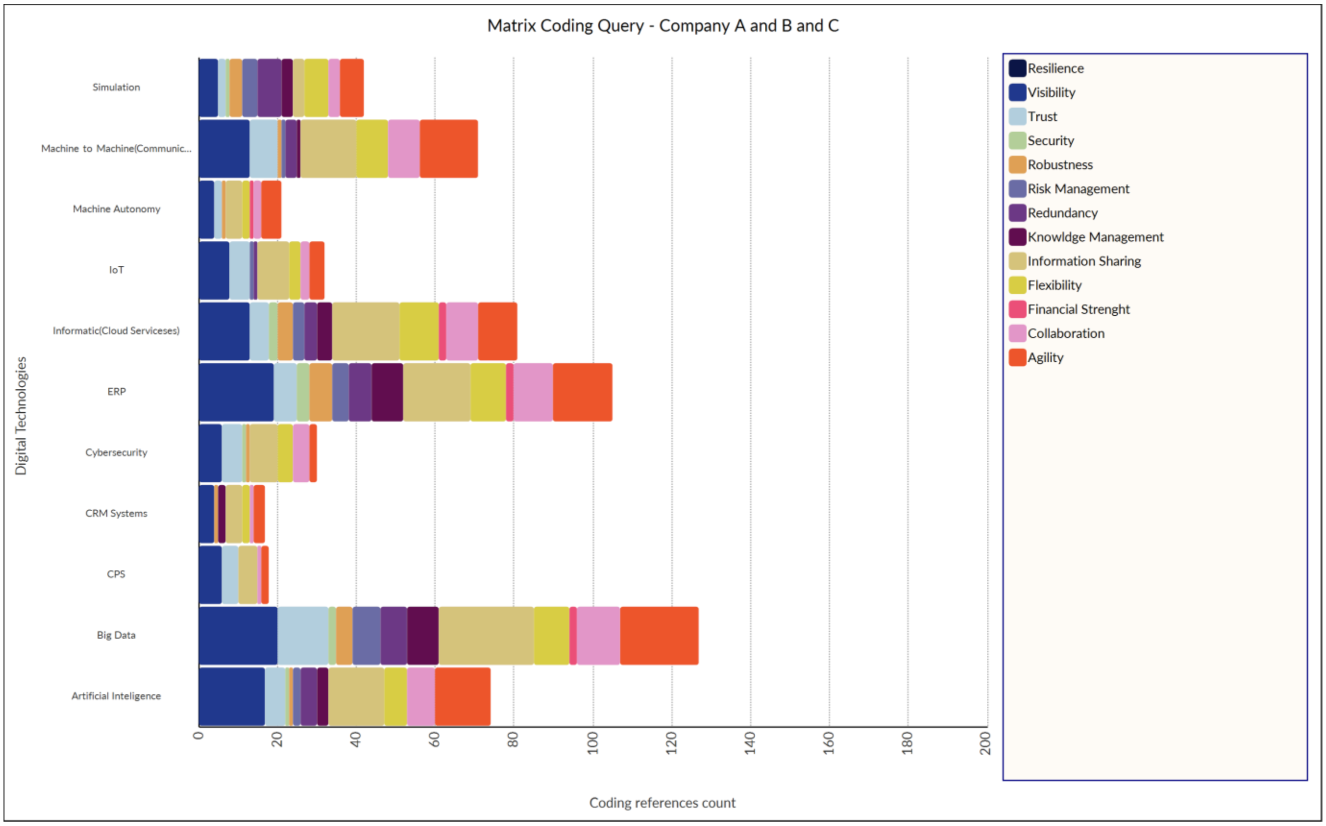

Figure 5-4 Company A and B and C combine Matrix coding

This study which is based on the clustering concepts of digital technologies and elements of resilience found that the adoption, availability, and cost efficiency of big data, along with a much wider usage of cloud-based technologies and AI tools can improve supply chain resilience those technological elements are especially related to visibility, information sharing and agility which they are three most essential elements of resilient. Since the last major economic crisis, the state of the art for big data, AI, and cloud have improved fast, for all the obvious reasons—rapid digitalization, breakthroughs in machine learning, increasing availability of external data streams, and much qualitative and quantitative data. In general, big data, AI, cloud, and machine to machine communication has progressed from technologies watching list to must-haves, and pilot projects have given way to enterprise-wide deployments. One of the reasons that all of our cases less affected by pandemic recession was to implement the ERP system before and in the early state of the pandemic it means small to medium-size companies in Quebec now noticed about the role of the data in their organization and they will progress in this manner since those data should be transformed into a digestible form for improving decision-making AI tools can enable them to reach this goal. Big data has a relation with different elements of resilience visibility is one of the elements which improve by big data and ERP is the source for generating those data which could be internally and externally one area our firms struggle with is generating useful business intelligence from recorded data this area mostly related to AI and data modelling although those companies use the basic feature of AI which offers in the ERP systems but to evaluate accurately they need to upgrade their AI tools enable them to simulate accurately and improve their capabilities based on different scenarios which implemented in their model and updated regularly. Big data combines historical sales data with predictive technologies to assist inventory managers with estimates of how much to expect. As businesses are compelled to become more agile, a modernized cloud ERP system may assist them in gaining end-to-end visibility into their operations while new technology and automation can help to improve visibility, more time and resources will be required to maximize the value of the data collected, increasing efficiency, and addressing supply chain concerns. Those actions, allowing the supply chain to acquire enough products to fill the shelves without purchasing too much and discarding products. Supply chain managers are more interested in leveraging technology to help decision-making processes in order to identify possibilities and assess their potential of causing disruptions in this sense big data and AI tools could improve the resolution and enrich the decision. Big data increases the dataset for analysis beyond the usual internal data housed on ERP and supply chain management (SCM) systems. AI employs sophisticated analytical models on both new and existing data sources. This generates fresh insights that contribute to supply chain decision-making, from improving front-line operations to strategic decisions such as selecting the best supply chain operating models. Big analytics will also help logistics firms to deliver products with less delivery attempts by analyzing their data to forecast when a specific customer is more likely to be at its destination. Logistic companies can reduce expenses and carbon emissions on a more strategic level by selecting the appropriate means of transportation. A big consumer packaged goods (CPG) is investing in analytics to assist it identifies when items need to be sent quickly by truck and when they can be delivered slowly by barge or rail. Big Data also enables better risk analysis, allowing logistic companies to be better prepared to deal with the variables that come with producing and shipping product, such as complicated crew and driver schedules, perishable product conditions, damaged or mishandled product, insufficient safety stock, some of the unpredicted events, and avoid the risks if possible. Businesses can use Big Data and AI to stay ahead of the curve in providing excellent customer service by establishing a fully integrated supply chain that is optimized to deliver the experiences that today's consumers expect, which is the correct product delivered as quickly and cheaply as possible and in pristine condition. Figure 5-5 depicts the relationship of most important digital technology elements and the most important elements of resilience based on our data analysis.

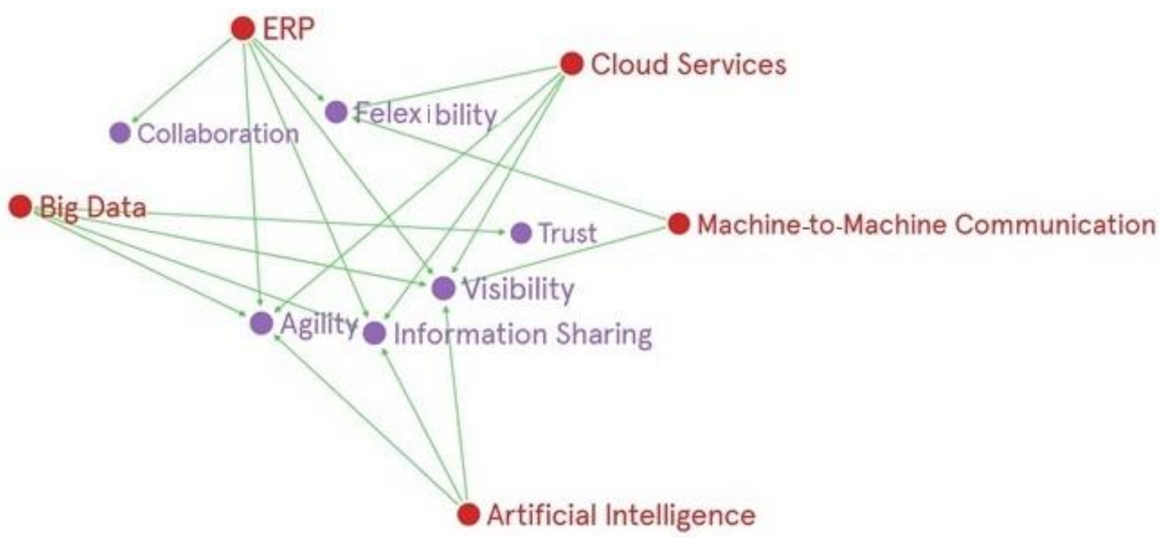

Figure 5-5 Relationship of digital technologies and elements of resilience

The capacity to minimize interruptions has been boosted by the emergence of predictive analytics and big data, which anticipate shifts in consumer demand, predict raw material availability, and help prepare businesses for catastrophic catastrophes. Machine learning will soon be able to connect real-time supplier data such as stock inventories and shipping trackers with external weather and news sources in order to make better, quicker decisions. Indeed, near-real-time monitoring and tracking in our supply chains may already provide rapid insights, reducing reaction times from days or weeks to hours or minutes. This is feasible because today's businesses have access to data that was previously unrecorded, and AI tools allowing them to get insights that keep their supply chain running properly from material receiving through product manufacture and storage to shipment to customers. In a nutshell, big data aids in the improvement of agility and flexibility in supply chain management in addition information sharing and risk management will be improving transparency since the customers have some knowledge about their orders. Other technologies have their impact on supply chain resilience, however, in our cases more than half of the effects in all the resilience elements come from

Big Data, AI, Cloud and ERP with Machine-to-Machine communication shows that digital technologies are vital for improving the supply chain resilience in the modern era. Poor communication with suppliers and customers reduces supply chain visibility and exposes the company to delays. In addition to adopting technologies that allow the firm to track supplier performance and respond based on real-time data, the company should maintain tight contact with its suppliers as well as customers. By establishing partnerships with suppliers, companies may keep each other informed of issues that may affect delivery and discuss solutions to those issues and simultaneously reporting to the customer. Customers nowadays demand to be kept informed on the status of their packages. Modern technology enables organizations to eliminate data centres and increase supply chain visibility. Informing the consumer when an issue is discovered that may affect the arrival of their product will save them from becoming dissatisfied as they wait for a shipping notice that never arrives. Building this level of transparency and visibility is important since visibility is critical for almost every operation. Complete supply chain visibility involves the ability to identify every connection in the supply chain network. This means acquiring complete transparency across the whole supply chain, from raw materials and components to subassemblies and client delivery. This visibility and transparency in the supply chain have the unintended consequence of increasing the overall efficiency of the operation and decreasing the issues created by disruptions. Real-time connectivity, predictive analysis, machine learning, and artificial intelligence (AI) in the supply chain would go a long way toward facilitating greater uniformity, transparency, and informed decision-making in the supply chain and enable decision-making more proactively against reactively. This study finds the strong relation of Big Data, AI, ERP and Cloud system and Machine to Machine communication with supply chain resilient elements mostly in visibility, information sharing, agility and flexibility in Canadian case and each company validate for the result throw supply chain. AI, ERP, Cloud, and M2M digital technologies would make all important data easily available, allowing planners to focus on minimizing disruption. Integrate digital technology across the supply chain could create more harmonization and transparency, as well as to effectively business management and continuity in disruption. This study validates internally alongside on each other and external in comparison with other cases which cited in the next chapter. While there is evidence which shows that all the elements in the supply chain validate each other, there is some differences and those defences related to the nature of company and their supply chain design since the operation of them is different from Company C which is a manufacturer and it is in the early stage of digital development to the Company B which is working in the field of logistics which relies on data and not fully connected for enhancing data decision algorithms. Finally, Company A is connected to different platforms and exchange data and consider to implement data decision models in their supply chain, furthermore, since the companies have different operation systems the pandemic has different effects on their supply chain for instance Company C suffer from lack of raw material and Company B face with the container shortage and Company A face with the increase of demand accordingly each company consider the pandemic as a challenge in their system.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

COVID-19 has drastically disrupted supply chain networks by increasing product demand while lowering raw material availability. In the case of the pet food market, it has not only survived COVID-19, but has thrived. To illustrate that, according to Packaged Facts (2021), retail sales of pet food (dog and cat) in the United States reached $37.1 billion in 2021, a 6.4 percent increase over 2020. Sales are expected to reach $47.9 billion by 2025, representing a 6.6 percent compound annual growth rate. That does not mean that the industry was not impacted by the crisis, but that it was able to respond to the increasing demand in spite of it. This was just possible because companies have been compelled to think differently and look for new opportunities to strengthen their supply networks. Supply chains are a complex network of supply channels that feed each other in such a way that a little interruption can have far-reaching consequences. Digital and communication technologies have then the potential to enhance supply chains by enabling real-time personalized solutions. This shift has the potential to enhance the supply chains, particularly when it comes to managing stocks, transportation, and contracting procedures on a global scale. With those technologies, the supply chain is able to prepare for and adapt to unexpected events, as well as quickly adjust to sudden disruptive changes that negatively affect supply chain performance; to continue operating during disruption and quickly recover to its pre-disruption state or a more desirable state, and to improve performance and long-term sustainability.

A case study of a sustainable pet food supply chain in Québec was analyzed to discover linkages between the cluster of digital technologies and cluster of resilience elements towards the COVID-19 pandemic. The findings of this study show that digital and connectivity technologies (such as ERP systems, Big data, cloud computing, Machine to Machine communication, AI, and predictive analytics), which are based on the translation of data into information and knowledge, based on our study those technologies make the supply chain more resilient specifically resilient in Agility, Information sharing, Visibility and Flexibility since those data and information allowing companies to keep up with the rate of disruption in the pandemic have a better view over the disruption and able to make a predictive modelling based on real time and historical data. Supply chain management digitization enables planning, sourcing, and logistics teams to interact, automate, and efficiently employ data. It has also demonstrated the ability to generate growth, minimize risk, and optimize expenses. Assessing the technological adoption in companies should enable decision makers to understand better the relationship between their technological advances and their supply chain resilience. Increasing digital technologies specifically Big Data, AI, Cloud plays an important role in managing potential supply chain disruptions in the future. According to the study's conclusions, big data adoption, availability, and cost efficiency, as well as a much broader usage of cloud-based technology and AI tools, can boost supply chain resilience which internally validate by each element of supply chain for external validation I refer to a study by Deloitte under the name of “Building Supply Chain Resilience beyond COVID-19”and this study shows the relationship of digital technology and supply chain resilience.

There are several conceptual and practical limitations for implementing all digital technologies one of the key obstacles to implementing Industry 4.0 and digital technologies is a shortage of trained labour, as well as the need to retrain employees to match altered conditions. Another key impediment to adoption is a scarcity of financial resources. Furthermore, insufficient levels of standardization, a lack of knowledge of integration, and data security concerns may hinder digital transformation adoption. The evolution of industrial systems has a substantial impact on the risk of fragility, adding to the ecosystem's unpredictability. One of the most significant impediments was the requirement for technical integration. The construction of a flexible interface is required for the successful integration of components, tools, and procedures. It is also critical to highlight the importance of corporate culture in change. In this study one important limitation was access to each company KPIs since those show the performance of a company and illustrate their bottlenecks. Furthermore, this research is validated by one external paper although there are a couple of the company managers explain the role of digital technology in supply chain resilience specifically in a pandemic situation the external validation limited to this paper. Now is the greatest moment for companies re-evaluating their supply chains to set their strategies into action. The pandemic emphasizes the need for reliable, real-time information that may assist organizations in making more educated decisions. Today, digital supply chain transformation is one of the most effective and secure strategies to develop a resilient organization.

This research project is not free from limitations, much on the contrary. For reasons beyond our control, we could not reach data saturation, and some players of the supply chain could not be reached, which significantly limits the generalization of our findings, even within the limits of this specific supply chain; much less can be said about the generalization of our findings for other supply chains. Another source of limitation is the fact that we only assessed digital technology ‘adoption’ and not digital ‘maturity’, which would probably allow us to gain much more meaningful insights. The reason for that is that digital maturity assessment would require conducting a technical diagnosis within each participating company, which was not possible due the limitations in terms of time and availability of the companies. We must also acknowledge that some terms may also be subject to the subjectivity of the respondents. Just to mention one example, the term "big data" is a buzzword that is not correctly understood by everyone. Even though we took some measures to prevent this, it is still possible that some respondents assumed to perform "big data", but in reality, they just perform analysis of "a lot of data", which is not necessarily the same thing. In spite of those limitations, we have contributed to the advancement of our current knowledge about the bonds between digitalization and resilience.

For the continuation of this research, we suggest that data collection is complemented with the missing links of the supply chain that could not be reached in the timeframe of this research. We also suggest that more interviews are conducted, so to reach data saturation. Another improvement would be to perform a digital maturity assessment rather than a simple observation of the technologies that were adopted. For future studies beyond the scope of this present research, we suggest that other supply chains be studied, and the results compared with the ones we obtained in this research. Another suggestion is to perform a more comprehensive and quantitative investigation with a larger number of companies, using different methods, e.g., a survey-based research.

REFERENCES

Agarwal, A., Shankar, R., & Tiwari, M. (2007). Modeling agility of supply chain. Industrial Marketing Management, 36(4), 443–457. https://doi.org/10.1016/j.indmarman.2005.12.004

Ahuett-Garza, H., & Kurfess, T. (2018). A brief discussion on the trends of habilitating technologies for Industry 4.0 and Smart manufacturing. Manufacturing Letters, 15, 60–63. https://doi.org/10.1016/j.mfglet.2018.02.011

Ali, A., Mahfouz, A., & Arisha, A. (2017). Analysing supply chain resilience: integrating the constructs in a concept mapping framework via a systematic literature review. Supply Chain Management: An International Journal, 22(1), 16–39. https://doi.org/10.1108/scm-06-2016-0197

Alicke, K., & Luchtenberg, D. (2021, December 8). Supply-chain resilience: Is there a holy grail? McKinsey & Company. https://www.mckinsey.com/business-functions/operations/our-insights/supply-chain-resilience-is-there-a-holy-grail

Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. Computer Networks, 54(15), 2787–2805. https://doi.org/10.1016/j.comnet.2010.05.010

Ambulkar, S., Blackhurst, J., & Grawe, S. (2014). Firm's resilience to supply chain disruptions: Scale development and empirical examination. Journal of Operations Management, 33–34(1), 111–122. https://doi.org/10.1016/j.jom.2014.11.002

Allam, Z., & Jones, D. S. (2021). Future (post-COVID) digital, smart and sustainable cities in the wake of 6G: Digital twins, immersive realities and new urban economies. Land Use Policy, 101, 105201. https://doi.org/10.1016/j.landusepol.2020.105201

Almajali, D. A., Masa'deh, R., & Tarhini, A. (2016). Antecedents of ERP systems implementation success: a study on Jordanian healthcare sector. Journal of Enterprise Information Management, 29(4), 549–565. https://doi.org/10.1108/jeim-03-2015-0024

Bartneck, C., Lütge, C., Wagner, A., & Welsh, S. (2020). An Introduction to Ethics in Robotics and AI (SpringerBriefs in Ethics) (1st ed. 2021 ed.). Springer.

Beuren, I., Santos, V., & Bernd, D. (2020). Effects of the Management Control System on Empowerment and Organizational Resilience. Brazilian Business Review, 17(2), 211–232. https://doi.org/10.15728/bbr.2020.17.2.5

Bibby, L., & Dehe, B. (2018). Defining and assessing industry 4.0 maturity levels – case of the defence sector. Production Planning & Control, 29(12), 1030–1043. https://doi.org/10.1080/09537287.2018.1503355

Birks, M., & Mills, J. (2015). Grounded Theory: A Practical Guide (Second ed.). SAGE Publications Ltd.

Billings, S. A. (2013). Nonlinear System Identification: NARMAX Methods in the Time, Frequency, and Spatio-Temporal Domains (1st ed.). Wiley.

Bjelland, E., & Haddara, M. (2018). Evolution of ERP Systems in the Cloud: A Study on System Updates. Systems, 6(2), 22. https://doi.org/10.3390/systems6020022

Bode, C., Wagner, S. M., Petersen, K. J., & Ellram, L. M. (2011). Understanding Responses to Supply Chain Disruptions: Insights from Information Processing and Resource Dependence Perspectives. Academy of Management Journal, 54(4), 833–856. https://doi.org/10.5465/amj.2011.64870145

Borrelli, A., & Wellmann, J. (2019). Computer Simulations Then and Now: an Introduction and Historical Reassessment. NTM Zeitschrift Für Geschichte Der Wissenschaften, Technik Und Medizin, 27(4), 407–417. https://doi.org/10.1007/s00048-019-00227-6

Boyes, H., Hallaq, B., Cunningham, J., & Watson, T. (2018). The industrial internet of things (IIoT): An analysis framework. Computers in Industry, 101, 1–12. https://doi.org/10.1016/j.compind.2018.04.015

Brandon-Jones, E., Squire, B., Autry, C. W., & Petersen, K. J. (2014). A Contingent Resource-Based Perspective of Supply Chain Resilience and Robustness. Journal of Supply Chain Management, 50(3), 55–73. https://doi.org/10.1111/jscm.12050

Breur, T. (2016). Statistical Power Analysis and the contemporary "crisis" in social sciences. Journal of Marketing Analytics, 4(2–3), 61–65. https://doi.org/10.1057/s41270-016-0001-3

Brusset, X., & Teller, C. (2017). Supply chain capabilities, risks, and resilience. International Journal of Production Economics, 184, 59–68. https://doi.org/10.1016/j.ijpe.2016.09.008

Building Supply Chain Resilience beyond COVID-19. (2020, December 9). Deloitte Switzerland. https://www2.deloitte.com/ch/en/pages/consumer-industrial-products/articles/building-supply-chain-resilience-beyond-covid-19.html

Cao, M., & Zhang, Q. (2010). Supply chain collaboration: Impact on collaborative advantage and firm performance. Journal of Operations Management, 29(3), 163–180. https://doi.org/10.1016/j.jom.2010.12.008

Cardona, O. D., van Aalst, M. K., Birkmann, J., Fordham, M., McGregor, G., Perez, R., Pulwarty, R. S., Schipper, E. L. F., Sinh, B. T., Décamps, H., Keim, M., Davis, I., Ebi, K. L., Lavell, A., Mechler, R., Murray, V., Pelling, M., Pohl, J., Smith, A. O., & Thomalla, F. (2012). Determinants of Risk: Exposure and Vulnerability. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, 65–108. https://doi.org/10.1017/cbo9781139177245.005

Chan, F. T., & Prakash, A. (2012). Inventory management in a lateral collaborative manufacturing supply chain: a simulation study. International Journal of Production Research, 50(16), 4670–4685. https://doi.org/10.1080/00207543.2011.628709

Christopher, M., & Peck, H. (2004). Building the Resilient Supply Chain. The International Journal of Logistics Management, 15(2), 1–14. https://doi.org/10.1108/09574090410700275

Chouhan, S., Mehra, P., and Dasot, A. (2017). India's Readiness for Industry 4.0: A Focus on Automotive Sector. Grant Thornton India LLP. https://www.grantthornton.in/insights/articles/indias-readiness-for-industry-4.0–a-focus-on-automotive-sector/.March 3, 1-46.

Chun Tie, Y., Birks, M., & Francis, K. (2019). Grounded theory research: A design framework for novice researchers. SAGE Open Medicine, 7, 205031211882292. https://doi.org/10.1177/2050312118822927

Copeland, B. (Invalid Date). artificial intelligence. Encyclopedia Britannica. https://www.britannica.com/technology/artificial-intelligence

Danjou, C., Pellerin, R., & Rivest, L. (2017). Le passage au numérique : Industrie 4.0 : des pistes pour aborder l'ère du numérique et de la connectivité.

de Paula Ferreira, W., Armellini, F., & de Santa-Eulalia, L. A. (2020). Simulation in industry 4.0: A state-of-the-art review. Computers & Industrial Engineering, 149, 106868. https://doi.org/10.1016/j.cie.2020.106868

Dwivedi, Y. K., Hughes, D. L., Coombs, C., Constantiou, I., Duan, Y., Edwards, J. S., Gupta, B., Lal, B., Misra, S., Prashant, P., Raman, R., Rana, N. P., Sharma, S. K., & Upadhyay, N. (2020). Impact of COVID-19 pandemic on information management research and practice: Transforming education, work and life. International Journal of Information Management, 55, 102211. https://doi.org/10.1016/j.ijinfomgt.2020.102211

Egbon, O. K. (2020). Cloud ERP in Malaysia: Benefits, Challenges, and Opportunities. International Journal of Advanced Trends in Computer Science and Engineering, 9(5), 7510–7516. https://doi.org/10.30534/ijatcse/2020/85952020

Fan, Y., & Stevenson, M. (2018). A review of supply chain risk management: definition, theory, and research agenda. *International Journal of Physical Distribution & Logistics* Management, 48(3), 205–230. https://doi.org/10.1108/ijpdlm-01-2017-0043

Fatorachian, H., & Kazemi, H. (2020). Impact of Industry 4.0 on supply chain performance. Production Planning & Control, 32(1), 63–81. https://doi.org/10.1080/09537287.2020.1712487

Fraga-Lamas, P., Fernandez-Carames, T. M., Blanco-Novoa, O., & Vilar-Montesinos, M. A. (2018). A Review on Industrial Augmented Reality Systems for the Industry 4.0 Shipyard. IEEE Access, 6, 13358–13375. https://doi.org/10.1109/access.2018.2808326

Frederico, G. F. (2021). Towards a Supply Chain 4.0 on the post-COVID-19 pandemic: a conceptual and strategic discussion for more resilient supply chains. Rajagiri Management Journal, 15(2), 94–104. https://doi.org/10.1108/ramj-08-2020-0047

Fletcher, G., & Griffiths, M. (2020). Digital transformation during a lockdown. International Journal of Information Management, 55, 102185. https://doi.org/10.1016/j.ijinfomgt.2020.102185

Galvão Scheidegger, A. P., Fernandes Pereira, T., Moura De Oliveira, M. L., Banerjee, A., & Barra Montevechi, J. A. (2018). An introductory guide for hybrid simulation modelers on the primary simulation methods in industrial engineering identified through a systematic review of the literature. Computers & Industrial Engineering, 124, 474–492. https://doi.org/10.1016/j.cie.2018.07.046

Ghadimi, P., Wang, C., Lim, M. K., & Heavey, C. (2019). Intelligent sustainable supplier selection using multi-agent technology: Theory and application for Industry 4.0 supply chains. Computers & Industrial Engineering, 127, 588–600. https://doi.org/10.1016/j.cie.2018.10.050

Gillis, A. S. (2021, August 13). What is internet of things (IoT)? IoT Agenda. https://internetofthingsagenda.techtarget.com/definition/Internet-of-Things-IoT

Glaser, B. G., & Strauss, A. L. (2017). Discovery of Grounded Theory: Strategies for Qualitative Research (1st ed.). Routledge.

Gonzalez, R.V., & Martins, M.F. (2017). Knowledge Management Process: a theoretical-conceptual research.

Gunasekeran, D., Tham, Y.-C., Ting, D. S. W., Tan, G. S. W., & Wong, T. Y. (2021). Digital health during COVID-19: lessons from operationalising new models of care in ophthalmology. The Lancet Digital Health 3(2) e124-e134.Hart, C. (2020, March 16). Nine in 10 supply chains hit by coronavirus. Supply Management. https://www.cips.org/supply-management/news/2020/march/nine-in-10-supply-chains-hit-by-coronavirus/

Hermann, M., Pentek, T., & Otto, B. (2016). Design Principles for Industrie 4.0 Scenarios. 2016 49th Hawaii International Conference on System Sciences (HICSS). Published. https://doi.org/10.1109/hicss.2016.488

Hevner, March, Park, & Ram. (2004). Design Science in Information Systems Research. MIS Quarterly, 28(1), 75. https://doi.org/10.2307/25148625

Hylving, L., & Schultze, U. (2013). Evolving the Modular Layered Architecture in Digital Innovation: The Case of the Car's Instrument Cluster. ICIS.

Iakovou, E., & White, C. C., III. (2020, December 3). How to build more secure, resilient, next-gen U.S. supply chains. Brookings. https://www.brookings.edu/techstream/how-to-build-more-secure-resilient-next-gen-u-s-supply-chains/

Ivanov, D., Dolgui, A., & Sokolov, B. (2018). The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. International Journal of Production Research, 57(3), 829–846. https://doi.org/10.1080/00207543.2018.1488086

Ivanov, D., Tang, C. S., Dolgui, A., Battini, D., & Das, A. (2020). Researchers' perspectives on Industry 4.0: multi-disciplinary analysis and opportunities for operations management. International Journal of Production Research, 59(7), 2055–2078. https://doi.org/10.1080/00207543.2020.1798035

J. Becker, R. Knackstedt, and J. Pöppelbuß, "Developing Maturity Models for IT Management," Bus. Inf. Syst. Eng., vol. 1, no. 3, pp. 213–
222, 2009.

Kamalahmadi, M., & Mellat-Parast, M. (2015). Developing a resilient supply chain through supplier flexibility and reliability assessment. International Journal of Production Research, 54(1), 302–321. https://doi.org/10.1080/00207543.2015.1088971

Karl, A. A., Micheluzzi, J., Leite, L. R., & Pereira, C. R. (2018). Supply chain resilience and key performance indicators: a systematic literature review. Production, 28(0). https://doi.org/10.1590/0103-6513.20180020

Karmaker, C. L., Ahmed, T., Ahmed, S., Ali, S. M., Moktadir, M. A., & Kabir, G. (2021). Improving supply chain sustainability in the context of COVID-19 pandemic in an emerging economy: Exploring drivers using an integrated model. Sustainable Production and Consumption, 26, 411–427. https://doi.org/10.1016/j.spc.2020.09.019

Kohlegger, M., Maier, R.K., & Thalmann, S. (2009). Understanding Maturity Models Results of a Structured Content Analysis.

Kovács, G., Benotsmane, R., & Dudás, L. (2019). THE CONCEPT OF AUTONOMOUS SYSTEMS IN INDUSTRY 4.0. Advanced Logistic Systems - Theory and Practice, 12(1), 77–87. https://doi.org/10.32971/als.2019.006

L. (2019, August 27). ERP Automation Benefits and Trends. Robotics & Automation News. https://roboticsandautomationnews.com/2019/08/27/erp-automation-benefits-and-trends/25196/

Leary, M. (2020). AM production economics. Design for Additive Manufacturing, 7–31. https://doi.org/10.1016/b978-0-12-816721-2.00002-6

Lechler, S., Canzaniello, A., Roßmann, B., von der Gracht, H. A., & Hartmann, E. (2019). Real-time data processing in supply chain management: revealing the uncertainty dilemma. International Journal of Physical Distribution & Logistics Management, 49(10), 1003–1019. https://doi.org/10.1108/ijpdlm-12-

2017-0398

Lee, E. A., & Seshia, S. A. (2016). Introduction to Embedded Systems, Second Edition: A Cyber-Physical Systems Approach (The MIT Press) (Second ed.). The MIT Press.

Lee, J., Bagheri, B., & Kao, H. A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters, 3, 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001

Li, D., Tang, H., Wang, S., & Liu, C. (2017). A big data enabled load-balancing control for smart manufacturing of Industry 4.0. Cluster Computing, 20(2), 1855–1864. https://doi.org/10.1007/s10586-017-0852-1

Leung, L. (2015). Validity, reliability, and generalizability in qualitative research. Journal of Family Medicine and Primary Care, 4(3), 324. https://doi.org/10.4103/2249-4863.161306

Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., Schmitt, K., Schmitz, E., & Schröter, M. (2015). INDUSTRIE 4.0 READINESS. MA's IMPULS-Stiftung. https://industrie40.vdma.org/documents/4214230/26342484/Industrie_40_Readiness_Study_1529498007918.pdf

Lin, C. T., Chiu, H., & Chu, P. Y. (2006). Agility index in the supply chain. International Journal of Production Economics, 100(2), 285–299. https://doi.org/10.1016/j.ijpe.2004.11.013

Lotfi, Z., Mukhtar, M., Sahran, S., & Zadeh, A. T. (2013). Information Sharing in Supply Chain Management. Procedia Technology, 11, 298–304. https://doi.org/10.1016/j.protcy.2013.12.194
Machine-to-Machine Communications. (2012). OECD Digital Economy Papers. https://doi.org/10.1787/5k9gsh2gp043-en

Lynch, D. J. (2021, January 24). Pandemic aftershocks overwhelm global supply lines. Washington Post. https://www.washingtonpost.com/business/2021/01/24/pandemic-shipping-economy/

Mell, P. M., & Grance, T. (2011). The NIST definition of cloud computing. The NIST Definition of Cloud Computing (Technical Report). https://doi.org/10.6028/nist.sp.800-145

Mitchell, J. C. (1983). Case and Situation Analysis. The Sociological Review, 31(2), 187–211. https://doi.org/10.1111/j.1467-954X.1983.tb00387.x

Midoux, C. (2020). How Industry 4.0 is making supply chains more agile and flexible. Consultancy.Eu. https://www.consultancy.eu/news/4538/how-industry-40-is-making-supply-chains-more-agile-and-flexible

Miles, M. B., Huberman, M. A., & Saldana, J. (2019). Qualitative Data Analysis: A Methods Sourcebook (4th ed.). SAGE Publications, Inc.

Mitroff, I. I. (1974). On doing Empirical Philosophy of Science: A Case Study in the Social Psychology of Research. Philosophy of the Social Sciences, 4(2–3), 183–196. https://doi.org/10.1177/004839317400400205

Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2017). The industrial management of SMEs in the era of Industry 4.0. International Journal of Production Research, 56(3), 1118–1136. https://doi.org/10.1080/00207543.2017.1372647

Møller, C. (2005). ERP II: a conceptual framework for next-generation enterprise systems? Journal of Enterprise Information Management, 18(4), 483–497. https://doi.org/10.1108/17410390510609626

Monostori, L., Váncza, J., & Kumara, S. (2006). Agent-Based Systems for Manufacturing. CIRP Annals, 55(2), 697–720. https://doi.org/10.1016/j.cirp.2006.10.004

Montazerolghaem, A., Yaghmaee, M. H., & Leon-Garcia, A. (2020). Green Cloud Multimedia Networking: NFV/SDN Based Energy-Efficient Resource Allocation. IEEE Transactions on Green Communications and Networking, 4(3), 873–889. https://doi.org/10.1109/tgcn.2020.2982821

Mubarik, M. S., Naghavi, N., Mubarik, M., Kusi-Sarpong, S., Khan, S. A., Zaman, S. I., & Kazmi, S. H. A. (2021). Resilience and cleaner production in industry 4.0: Role of supply chain mapping and visibility. Journal of Cleaner Production, 292, 126058. https://doi.org/10.1016/j.jclepro.2021.126058

Packaged Facts (2021) U.S. Pet Market Focus: Pet Food Update, 2021 : Market Research Report.Available: https://www.packagedfacts.com/Pet-Focus-Food-Update-30288693/

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2013). Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. Administration and Policy in Mental Health and Mental Health Services Research, 42(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Parello, J., Claise, B., Schoening, B., & Quittek, J. (2014). Energy Management Framework. Energy Management Framework. https://doi.org/10.17487/rfc7326

Parker, H., & Ameen, K. (2018). The role of resilience capabilities in shaping how firms respond to disruptions. Journal of Business Research, 88, 535–541. https://doi.org/10.1016/j.jbusres.2017.12.022

PCMag. (2022). Definition of SaaS. https://www.pcmag.com/encyclopedia/term/saas

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. Journal of Management Information Systems, 24(3), 45–77. https://doi.org/10.2753/mis0742-1222240302

Pettit, T. J., Croxton, K. L., & Fiksel, J. (2013). Ensuring Supply Chain Resilience: Development and Implementation of an Assessment Tool. Journal of Business Logistics, 34(1), 46–76. https://doi.org/10.1111/jbl.12009

Pettit, T. J., Fiksel, J., & Croxton, K. L. (2010). ENSURING SUPPLY CHAIN RESILIENCE: DEVELOPMENT OF A CONCEPTUAL FRAMEWORK. Journal of Business Logistics, 31(1), 1–21. https://doi.org/10.1002/j.2158-1592.2010.tb00125.x

Pramanik, P. K. D., Mukherjee, B., Pal, S., Upadhyaya, B. K., & Dutta, S. (2019). Ubiquitous Manufacturing in the Age of Industry 4.0: A State-of-the-Art Primer. A Roadmap to Industry 4.0: Smart Production, Sharp Business and Sustainable Development, 73–112. https://doi.org/10.1007/978-3-030-14544-6_5

Pereira, C. R., Lago da Silva, A., Tate, W. L., & Christopher, M. (2020). Purchasing and supply management (PSM) contribution to supply-side resilience. International Journal of Production Economics, 228, 107740. https://doi.org/10.1016/j.ijpe.2020.107740

Pettit, T. J., Croxton, K. L., & Fiksel, J. (2019). The Evolution of Resilience in Supply Chain Management: A Retrospective on Ensuring Supply Chain Resilience. Journal of Business Logistics, 40(1), 56–65. https://doi.org/10.1111/jbl.12202

Pfeiffer, B. (2020, April 7). COVID-19: Managing supply chain risk and disruption. Deloitte Switzerland. https://www2.deloitte.com/ch/en/pages/risk/articles/covid-19-managing-supply-chain-risk-and-disruption.html

Pisano, P. G. (2015). You Need an Innovation Strategy. Harvard Business Review. https://www.hbs.edu/faculty/Pages/item.aspx?num=49244

Ponomarov, S. Y., & Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. The International Journal of Logistics Management, 20(1), 124–143. https://doi.org/10.1108/09574090910954873

PWC. (2016). Industry 4.0: Building the digital enterprise. https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf

Ralph, N., Birks, M., & Chapman, Y. (2015). The Methodological Dynamism of Grounded Theory. International Journal of Qualitative Methods, 14(4), 160940691561157. https://doi.org/10.1177/1609406915611576

Ralston, P., & Blackhurst, J. (2020). Industry 4.0 and resilience in the supply chain: a driver of capability enhancement or capability loss? International Journal of Production Research, 58(16), 5006–5019. https://doi.org/10.1080/00207543.2020.1736724

Rao, S., & Goldsby, T. J. (2009). Supply chain risks: a review and typology. The International Journal of Logistics Management, 20(1), 97–123. https://doi.org/10.1108/09574090910954864

Ray, P.P.. (2016). A Survey on Internet of Things Architectures. EAI Endorsed Transactions on Internet of

Things. 2. 151714. 10.4108/eai.1-12-2016.151714.

Roberta Pereira, C., Christopher, M., & Lago Da Silva, A. (2014). Achieving supply chain resilience: the role of procurement. Supply Chain Management: An International Journal, 19(5/6), 626–642. https://doi.org/10.1108/scm-09-2013-0346

Romascanu, D., Schoenwaelder, J., & Sehgal, A. (2015). Management of Networks with Constrained Devices: Use Cases. Management of Networks with Constrained Devices: Use Cases. https://doi.org/10.17487/rfc7548

Sahu, A. K., Datta, S., & Mahapatra, S. (2017). Evaluation of performance index in resilient supply chain: a fuzzy-based approach. Benchmarking: An International Journal, 24(1), 118–142. https://doi.org/10.1108/bij-07-2015-0068

Scavarda, L. F., CERYNO, P. S., PIRES, S., & KLINGEBIEL, K. (2015). SUPPLY CHAIN RESILIENCE ANALYSIS: A BRAZILIAN AUTOMOTIVE CASE. Revista de Administração de Empresas, 55(3), 304–313. https://doi.org/10.1590/s0034-759020150306

Schatz, D., Bashroush, R., & Wall, J. (2017). Towards a More Representative Definition of Cyber Security. The Journal of Digital Forensics, Security and Law. https://doi.org/10.15394/jdfsl.2017.1476

Schneider, P. (2018). Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field. Review of Managerial Science, 12(3), 803–848. https://doi.org/10.1007/s11846-018-0283-2

Scholten, K., Sharkey Scott, P., & Fynes, B. (2014). Mitigation processes – antecedents for building supply chain resilience. Supply Chain Management: An International Journal, 19(2), 211–228. https://doi.org/10.1108/scm-06-2013-0191

Schumacher, A., Erol, S., & Sihn, W. (2016). A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. Procedia CIRP, 52, 161–166. https://doi.org/10.1016/j.procir.2016.07.040

Schwab, K. (2016). The Fourth Industrial Revolution. World Economic Forum.

Secundo, G., MELE, G., VECCHIO, P. D., ELIA, G., MARGHERITA, A., & NDOU, V. (2021). Threat or opportunity? A case study of digital-enabled redesign of entrepreneurship education in the COVID-19 emergency. Technological Forecasting and Social Change, 166, 120565. https://doi.org/10.1016/j.techfore.2020.120565

Sharma, A., Rangarajan, D., & Paesbrugghe, B. (2020). Increasing resilience by creating an adaptive salesforce. Industrial Marketing Management, 88, 238–246. https://doi.org/10.1016/j.indmarman.2020.05.023

Simatupang, T. M., & Sridharan, R. (2005). The collaboration index: a measure for supply chain collaboration. International Journal of Physical Distribution & Logistics Management, 35(1), 44–62. https://doi.org/10.1108/09600030510577421

Snijders, C., Matzat, U., & Reips, U. (2012). "Big Data": big gaps of knowledge in the field of internet science.

Spieske, A., & Birkel, H. (2021). Improving supply chain resilience through industry 4.0: A systematic literature review under the impressions of the COVID-19 pandemic. Computers & Industrial Engineering, 158, 107452. https://doi.org/10.1016/j.cie.2021.107452

Sundmaeker, H., Guillemin, P., Friess, P., Woelfflé, S., European Commission. Directorate-General for the Information Society and Media, & European Commission. Directorate-General for the Information Society and Media. (2010). Vision and Challenges for Realising the Internet of Things. UTB.

Standard Terminology for Additive Manufacturing Technologies, (n.d.). ASTM. Retrieved, from https://www.astm.org/f2792-12.html

Supply Chain Transformation with Industry 4.0. (2021, September 21). KPMG. https://home.kpmg/ca/en/home/insights/2021/10/supply-chain-transformation-with-industry.html

Tang, C. S. (2006). Perspectives in supply chain risk management. International Journal of Production Economics, 103(2), 451–488. https://doi.org/10.1016/j.ijpe.2005.12.006 Teece, D. J. (1992). Competition, cooperation, and innovation. Journal of Economic Behavior & Organization, 18(1), 1–25. https://doi.org/10.1016/0167-2681(92)90050-l

Tao, F., Zhang, M., & Nee, A. (2019a). Digital Twin Driven Smart Manufacturing (1st ed.). Academic Press.

Terblanche, I. (2021, February 12). Building resilience into a Supply Chain 4.0 strategy. Supply Chain Digital. https://supplychaindigital.com/supply-chain-risk-management/building-resilience-supply-chain-40-strategy

Telmoudi, A. J., Bourjault, A., & Nabli, L. (2008). The use of redundancy to evaluate the manufacturing system total robustness: A quality approach. 2008 3rd International Symposium on Communications, Control and Signal Processing. Published. https://doi.org/10.1109/isccsp.2008.4537266

Tempelman, E., Shercliff, H., van Eyben, B. N., & van Eyben, B. N. (2014). Manufacturing and Design. Elsevier Gezondheidszorg.

The Oxford English Dictionary. (2022). John Simpson; Edmund Weiner - Oxford University Press. https://global.oup.com/academic/product/the-oxford-english-dictionary-9780198611868?cc=us&lang=en&

Valckenaers, P., & van Brussel, H. (2005). Holonic Manufacturing Execution Systems. CIRP Annals, 54(1), 427–432. https://doi.org/10.1016/s0007-8506(07)60137-1

Van Brussel, H., Wyns, J., Valckenaers, P., Bongaerts, L., & Peeters, P. (1998). Reference architecture for holonic manufacturing systems: PROSA. Computers in Industry, 37(3), 255–274. https://doi.org/10.1016/s0166-3615(98)00102-x

Vinodh, S., & Wankhede, V. A. (2020). Application of fuzzy DEMATEL and fuzzy CODAS for analysis of workforce attributes pertaining to Industry 4.0: A case study. International Journal of Quality & Reliability Management. https://doi.org/10.1108/IJQRM-09-2020-0322

Werner, M. J. E., Yamada, A. P. L., Domingos, E. G. N., Leite, L. R., & Pereira, C. R. (2020). Exploring Organizational Resilience Through Key Performance Indicators. Journal of Industrial and Production Engineering, 38(1), 51–65. https://doi.org/10.1080/21681015.2020.1839582

Whittemore, R., Chase, S. K., & Mandle, C. L. (2001). Validity in Qualitative Research. Qualitative Health Research, 11(4), 522–537. https://doi.org/10.1177/104973201129119299

Williams, D., II. (2017, December 7). The History of Augmented Reality (Infographic). HuffPost. https://www.huffpost.com/entry/the-history-of-augmented-_b_9955048

Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: state of the art and future trends. International Journal of Production Research, 56(8), 2941–2962. https://doi.org/10.1080/00207543.2018.1444806

Xu, Z., Elomri, A., Kerbache, L., & El Omri, A. (2020). Impacts of COVID-19 on Global Supply Chains: Facts and Perspectives. IEEE Engineering Management Review, 48(3), 153–166. https://doi.org/10.1109/emr.2020.3018420

Yadin, T. (2021, April 5). Revolutions are only visible in retrospect. Valor. https://blogs.sw.siemens.com/valor/2021/02/15/revolutions-are-only-visible-in-retrospect/

Yin, R. K. (2017). Case Study Research and Applications: Design and Methods (6th ed.). SAGE Publications, Inc.

Yoo, Y., Henfridsson, O., & Lyytinen, K. (2010). Research Commentary—The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research. Information Systems Research, 21(4), 724–735. https://doi.org/10.1287/isre.1100.0322

Zerbino, P., Aloini, D., Dulmin, R., & Mininno, V. (2021, December 16). Why enterprise resource planning initiatives do succeed in the long run: A case-based causal network. PLOS ONE, 16(12), e0260798. https://doi.org/10.1371/journal.pone.0260798

Zouari, D., Ruel, S., & Viale, L. (2020). Does digitalising the supply chain contribute to its resilience? International Journal of Physical Distribution & Logistics Management, 51(2), 149–180. https://doi.org/10.1108/ijpdlm-01-2020-0038

APPENDIX A INVITATION LETTER

(*Note: the letter is currently being translated by native French, Portuguese and Italian speakers and translations will be provided to the CÉR as soon as possible)

Dear Madam/Sir,

The purpose of this e-mail is to invite you to take part in a research project, whose goal is to conduct case studies to understand how digital technologies are being used by companies to build resilience and overcome the current pandemic situation we are living in.
To build these case studies, I aim ate conducting interviews with key human resources involved with supply chain, R&D and ICT management. Our goal with these interviews is to understand the impact that the COVID pandemic to the supply chain, and to understand how the pandemic situation changed the digital transformation strategies of the companies in the supply chain under study. I found your contact through internet and your company directory.
In the interview, I will discuss some of the supply management practices, digital technologies and ongoing digital transformation in your company, and the connection between both for building resilience.
The interview is confidential and should not take more than 1 hour and a half of your time. You will find attached the Informed Consent Form, where you will find more information about the project and the nature of your participation. Please take your time to read it carefully before accepting the invitation to participate. If you agree with the terms, I kindly ask you to sign the form and return for us for scheduling an appointment. Due to the current COVID-19 situation, the interview will take place in the videoconference platform of your choice.

This project was approved by Polytechnique Montréal's Research Ethics Board (certificate no. CER-2122-02-D attached). You can therefore be assured that your privacy will be respected, and that the data you provide us will be carefully handled, analyzed, and stored, and that only data in an aggregated form will be used for any publications resulting from this research project.

Should you have any questions about the research project, please feel free to contact us.

Once again, thank you very much in advance for your attention and for helping us by participating in the research.
Yours sincerely,
Parham Asgharifard

APPENDIX B INTERVIEW GUIDE

(*Note: the guide is currently being translated by native French, Portuguese and Italian speakers and translations will be provided to the CÉR as soon as possible)

1. General (10 min)

- Could you let us know about your overall view of your supply chain management structure and digital technologies?
- Could you tell us a little about your company operations and supply chain management before pandemic?
- Were you going through any improvement in digital transformation (technologies) before pandemic?

2. COVID-19 Impacts (20min)

- How was the initial impact (Positive and Negative) of COVID-19 on the operations of your company?
- How was your overall experience on COVID-19 pandemic period in supply chain management?
- When did it start to affect the company's operations?
- What kinds of actions/practices did you apply (and the whole company) in the first moment?
- Are there some key learning/takeaways that are incorporated into the stabilization process after each disruption? Is there a formal process for learning backup?

3. Recovery (15 min)

- Do your company operations get back to normal? If not, what stage is it in?
- How long do you think it will take to completely recover?
- Which factors make a role for recovery?
- What was the role of digital technologies for this recovery?
- What kinds of actions did you take to overcome this situation and recover your system?

4. Supply chain performance (15 min)

- How do you assess your supply chain performance?
- Do you assess your supply chain performance based on different scenarios?
- Do you assess information visibility?
- Do you evaluate the operational risks that threaten the supply chain?
- What digital technologies did you implement to that effect? (IoT, block chain, cloud-based supply chain, additive manufacturing, digital twins, RFID, AI, ERP system)

APPENDIX C INFORMATION AND CONSENT FORM

(*Note: this form is currently being translated by native French, Portuguese and Italian speakers and translations will be provided to the CÉR as soon as possible).

Information and Consent Form

Title of research project: Assessment of digital adoption as a factor to build responsiveness in global supply chains – the case of the COVID-19 pandemic crisis

Research Team:

Responsible of the research project

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Research project funding:

This research project is an independent initiative and does not count with any funding.

Conflicts of interest

The research team does not have a conflict of interest in terms of the present research project.

Preamble

I are inviting you to participate in a research project, whose goal is to explore the research question of whether and how digital adoption can be a factor for building supply chain resilience, and assess this relationship in the specific context of the COVID-19 pandemic crisis.

Prior to consenting to participating in this research project and signing this consent form, please take the time to fully read all the information provided.

I invite you to ask any and all questions you consider relevant to the research project supervisor, or to any team member, and to request clarification for any word or concept that is unclear to you. I also invite you to request guidance from any individual from whom you judge appropriate, in regards to your participation.

Overall presentation of the research project

The main objective of the research project is to empirically link digital adoption and supply chain resilience, which is precisely the gap that this qualitative and exploratory research project aims to fill. To achieve our objectives, a literature review was conducted to shed light on the interconnexions between supply-chain resilience and digital transformation. I are then performing multiple case studies to contrast the literature with practice during the COVID-19 pandemic crisis, using the Case Study Theory Methodology. To the case studies, I are conducting semi-structured interviews with stakeholders in Canada. The interview will also allow the research team to perform a digital adoption (Industry 4.0 readiness) assessment for the three supply chains under study.

Inclusion and exclusion criteria

For this research project, I are recruiting three individuals that are willing to participate and is directly involved in supply chain, R&D or ICT management of a company that is inserted in one of the three supply chains under study, and who has knowledge about the pre-pandemic and the current (pandemic) situation of the company. The participant must be 18 years old or older. There are non-exclusion criteria based on gender, religion, ethnicity, or disability.

Nature and duration of your participation in the research project

The interview will take place at least two days after the invitation to ensure that the participant will have enough time to read the document outlining the conditions for participating in the project.
I estimate that the interviews will take around 60 minutes of your time. During the interview, the researcher will ask you about the pre and post pandemic situation of your company, whether and how it was capable to overcome the challenges imposed by the pandemic, and also perform an assessment of your company's digital adoption and the role played by digital technologies to overcome the crisis.
Due to the COVID-19 pandemic, the interview will be conducted through videoconference platform of your preference (MS Teams, Zoom, Google Meet, Skype, or WebEx). For the cases where it is not possible to work remotely (e.g., site visits), all the precaution measures provided by Polytechnique Montreal Ethics

Committee and the Public Health Agency of Canada will be followed (e.g., wash hands regularly, clean work surfaces and shared equipment, maintain a 2-metre distance from others at all times, avoid direct physical contact, wear a procedure mask).

Risks and inconveniences that may stem from participation in this research project:

The research project does not have any specific risks. The only inconvenience is the time that will be spent during the interview.

Advantages that may stem from your participation in a research project

The participant will not derive any personal benefits from this research activity. Regardless, it will h permit advances in the fields of Industry 4.0 and supply chain resilience.

Financial Compensation

You will not receive any financial compensation from your participation in the present research project.

Compensation in the event of participant injury / damages

If your participation in the research project results in any injury whatsoever, you in no way wave your legal rights, nor relieve researchers, funding organizations, and Polytechnique Montréal of their professional and legal responsibilities.

Voluntary participation and possibility of ceasing participation:

Your participation in this research project is voluntary. Thus, you are free to cease participating at any time, and can decide to cease participation in the activity without having to justify yourself, and without risk of prejudice. To cease participation in the activity, please verbally notify the appropriate individual on the research team. In the event of withdrawal, the participant can request the destruction of the data. However, it will not be possible to remove the data or material from analyses once published or disseminated.

Confidentiality and protection of data:

The research responsible for the project will use all data for the sole purpose of the research project, which can be published in scientific journals. Only aggregated and anonymized data will be published. The data collected will be kept for a period of 7 years, after which it will be destroyed. The participant has the right to consult the research file to verify the accuracy of the information research team or Polytechnique Montréal has this information. However, to preserve the scientific integrity of the research project; some information will only be accessible at the end of the research project.
Throughout your participation in this research project, you will receive pertinent information relevant to your participation.
The research team and the *Comité d'éthique de la recherche* (Research Ethics Committee) reserve the right to remove you from a research project if you do not respect guidelines, if there are potential administrative reasons to remove you, if your participation is no longer safe, or for any other reason related to the feasibility of the research project. Should such a situation arise, the Research Team will inform you as quickly as possible.

Confidentiality and protection of personal information

The research team will collect and store all personal data in a secure manner, and will respect and protect its confidential nature.

During the interview, the researcher will ask for your permission to record the audio and the video of the interview No personal information will be required. The research responsible for the project will use all data for the sole purpose of the research project, which can be published in scientific journals.
During data analysis and transfer, the recorded audio and video will be stored in an encrypted folder stored on the researcher's personal computer responsible for the project, until the interview is transcribed into a text document. After transcription, the audio and video files will be destroyed.
After the research project has come to an end, the transcription of your interview will be stored by the Research Team for a period of 7 years.
You have the right to view your research data profile to verify the accuracy of information gathered for as long as the research team or Polytechnique Montréal have said information. Note however, that in order to preserve the scientific integrity of the research project, some information will only be accessible upon the research project's completion.

Dissemination of research results

The results of this research will be the object of a scientific paper to be published in journals specialized in supply chain and technology management. I will give you the opportunity to revise the text that refers to your company before submission of the manuscript to the journal. Besides, you will also be informed when the paper is published and I will provide you a copy of the paper.

Reference and resource people

If you have questions about **scientific aspects** of the research project, or to **cease participation** in the study, please contact: Parham Asgharifard via email at parham.asgharifard@polymtl.ca.

For all concerns regarding your rights or the responsibilities of the research team in regards to your participation in this project, you can contact the *Comité d'éthique de la recherche* at Polytechnique Montréal at 514-340-4711, ext. 4420 or via email at: ethique@polymtl.ca

Consent to participation in a research project

1. I have read and understood the attached documentation, which describes the nature and the process of the research project, as well as the risks and inconveniences that this project may incur.
2. I understand that I have the right to satisfactory answers in response to any questions that I have in regards to my involvement in this project, and this, throughout my participation therein.
3. I freely consent to participation in this research project, after having had the time to consider it, to my complete satisfaction. I confirm having felt no pressure to participate.
4. I understand that as a participant in this research project, I do not renounce any of my rights, nor do I waive researcher's legal responsibilities.
5. I understand that I can consult the research data profile that the research team has created with my data.
6. I can, at any time, with verbal warning, decide to immediately cease participation, and that at that time, I will immediately be freed from my commitment.
7. I have received a copy of the present document.

Video recording

I consent to have the interview recorded for transcription purposes only. Yes ☐ No ☐

____
Participant first and last name (block letters)

____
Participant signature

Date: ____________________________________

Research team commitment

I hereby confirm that I myself, or a representative, has explained to the above-mentioned individual the nature of their participation in the present research project, have asked if they have questions, and have answered any questions posed. I or we have clearly indicated that the individual remains free to cease participation in the study at any time, via simple verbal notification. I, along with the research team, commit to respecting the modalities described in the present consent and information form, and I declare having provided a signed copy of the latter to the individual concerned.

Parham Asgharifard
Researcher first and last name (block letters)

Parham Asgharifard
Researcher signature

Date: 2021/06/22____________________________________

APPENDIX D CODE BOOK

Table D-1 List of Code Book

Name	Description
Industry 4.0 and digital Technologies	Digital Technologies
Artificial Intelligence	Artificial intelligence (AI) was first coined in 1956, but thanks to increased data volumes, advanced algorithms, and advances in computing power and storage, AI is becoming more popular today.AI define as the capacity of a digital computer or a computer-controlled robot to do tasks that would normally be performed by intelligent individuals. The phrase is widely used to refer to a mission designed to generate systems with human-like cognitive abilities, such as the capacity to reason, discover meaning, generalise, and learn from prior experiences.
Augmented Reality	Augmented reality (AR) is an interactive experience of a real-world environment in which computer-generated perceptual information is used to augment the items in the real world, sometimes spanning many sensory modalities such as visual, aural, haptic, somatosensory, and olfactory. Augmented Reality (AR), and specifically Industrial Augmented Reality (IAR), is one of the technologies that can assist operators with tasks such as assembly, context-aware assistance, data visualisation and interaction (acting as a Human-Machine Interface (HMI)), indoor localization, maintenance applications, quality control, and material management.
Big Data	Big data is a discipline that deals with methods for analyzing, rationally extracting knowledge from data, or otherwise dealing with data volumes that are too massive or complicated for typical data-processing application software to handle. Data with a lot of columns has more statistical power for pattern recognition, however data with a lot of columns has a higher false discovery rate.
CPS	A CPS, or intelligent system, is a computer system in which computer-based algorithms regulate or monitor a mechanism or operation. Physical and software components are intricately linked in cyber-physical systems, allowing them to function on diverse dimensions, display many and unique behavioural modalities, and interact in ways that alter with setting.
Cybersecurity	The technique of securing critical systems and sensitive data against cyber-attack is known as cybersecurity. Cybersecurity measures, also known as information technology (IT) security, are meant to prevent threats to networked systems and applications, whether they come from within or outside of a company.
ERP	Enterprise resource planning (ERP) is an initial for enterprise resource planning (ERP). It is an element of business process management software that manages and connects a company's finances, supply chain, operations, commerce, reporting, manufacturing, and human resource functions. ERP is the integrated management system of the key business operations, which is typically done in real time and managed by software and technology. ERP is a type of business management solutions a set of linked applications that allows a company to gather, store, manage, and understand data from a variety of business processes.

Table D-1 List of Code Book (cont'd)

Name	Description
Informatic (Cloud Serviceses)	Cloud computing is a concept for providing on-demand network access to a shared of customizable computing resources (e.g., networks, servers, applications, and services) particularly data storage (cloud storage) computational power that could be instantly supplied and released with no administration effort or service provider involvement. computing providers offer their "services" according to different models, of which the three standard models per NIST are Infrastructure as a Service (IaaS), Platform as a Service (PaaS).
IoT	The Internet of Things (IoT) is a concept that indicates the link between the digital and physical worlds. The Internet of Things (IoT) defines physical items (or groups of such objects) equipped with sensors, processing capability, software, and other technologies that connect and exchange data with other devices and systems through the Internet or other communications networks.
Machine Autonomy	According to Industry 4.0 and digital technologies, the future of production is ubiquitous integration, in which all industrial parts autonomously communicate information, trigger operations, and control themselves. Machines are becoming increasingly autonomous and collaborative. Intelligent machines can communicate with one another to increase productivity and product. These machines are capable of doing more difficult tasks and dealing with unanticipated issues.
Machine to Machine (Communication)	Machine-to-machine (M2M) communication occurs when devices communicate directly with one another through any data transmission, including wired and wireless. M2M refers to a set of technologies that allow machines, devices, systems, and people to exchange data. M2M has a practically limitless number of uses. One example is traffic control, which involves devices exchanging data in order to control traffic flow. Security systems, vending machines, and data harvesting are among the others.
Simulation	Simulations are digital models that simulate the activities or processes of a system in computing. These simulations are used to analyse system performance as well as to test and implement innovative ideas. Engineers and professionals utilise simulations to test goods, systems, processes, and concepts in a range of sectors.
Additive Manufacturing	The ASTM society defines additive manufacturing (AM) as “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies”
Element of Resilience	Description
Agility	Capacity to react rapidly to changes, possibly reducing the effect of a potential interruption. One of the properties of an agile supply chain is the ability to boost speed in order to respond to changes.
Collaboration	Capacity to respond to supply chain disruptions via a collaborative strategy and understanding on how to organise a quick reaction. The most challenging task for managers is to enable collaborative setting.
Financial Strength	Financial strength refers to the ability to withstand cash flow variations, which has an impact on acquisition activity.

Table D-1 List of Code Book (cont'd and end)

Name	Description
Flexibility	Flexibility is defined as the ability to adjust to changing circumstances, whether through procedures, resources, goods, pricing, or transportation. In this regard, experts emphasise that flexibility refers to an organization's capacity to re manage its output in a cost-effective manner within a given time frame and interval.
Information Sharing	Supply chain partners sharing information on organisational assets to give visibility upstream and downstream (such as information about new project development or online order status).
Knowledge Management	It describes the methods for capturing information and experiences from lessons learnt, so that knowledge may be retained in the company's file rather than only in the minds of employees. Through gained experiences, such as training and information exchange, this seeks to assist managers in overcoming various forms of disruptions.
Redundancy	Expanded manufacturing, transportation, stock, and storage capacity that can aid in critical moments like supply disruptions. One option for overcoming the disturbances is to build resource redundancy across the supply chain.
Risk Management	Risk management is a reaction to high-unpredictability disturbances in the past, present, and future. As a result, when selecting which risks should be mitigated, minimised, or managed, its implementation tries to organise risk identification and measuring methods in order to maintain better responses.
Robustness	The ability of a supply chain to overcome the effects of various interruptions or to preserve process continuity. Developing resilience allows businesses to maintain their operational effectiveness while avoiding larger interruptions.
Security	Security is a key element for supply chains to be protected from the risks and faults they may be exposed to - cyberattacks or physical attacks.
Trust	Based on the assumption that partners will not act opportunistically, even if there are short-term incentives to do so, hence contributing considerably to the organization's and supply chain's long-term stability.
Visibility	visibility is defined as the capacity to identify dangers and events that might harm an organization's or supply chain's performance.
Supply Chain Design	Supply chain design focuses on location strategies to make the supply chains more robust, safe, and agile; if performed in real time, it is possible to prevent disruptions.