Impacts of Industry 4.0 Technologies on Supply Chain Resilience

Saeed Albeetar[1], Concetta Semeraro[1][a] and Giovanni Francesco Massari[2][b]

[1]*Department of Industrial Engineering and Engineering Management, University of Sharjah, Sharjah, U.A.E.*

[2]*Department of Mechanics, Mathematics, and Management, Politecnico di Bari, Bari, Italy*

Keywords: Resilience, Industry 4.0, Industry 4.0 Technologies, Supply Chain, Supply Chain Resilience Drivers.

Abstract: Disruptions in the supply chain are among the most dangerous events. Supply chains increasingly face a turbulent environment characterized by unpredictable disruptions that threaten the stability of industrial operations. Most companies face challenges in their supply chains. Resilience will help organizations transform and adapt their business to dynamic environments and recover quickly from difficulties and toughness. Recent technological progress, primarily Industry 4.0 (I4.0) technologies, indicates promising possibilities to mitigate supply chain risk. This paper will study the impact of Industry 4.0 technologies on supply chain resilience.

1 INTRODUCTION

Today firms operate in complex and turbulent environments characterized by disrupting events continuously threatening the stability of their operations, processes, and performance. Disruptions may vary in nature, as well as the probability of occurrence and the impact of their consequences. However, disruptions can also occur due to natural catastrophes, disasters, and economic disruptions such as hurricanes, earthquakes, floods, terrorist attacks, labour strikes, fuel crises, and financial crises (Spieske & Birkel, 2021). These events may cause adverse effects on supply chain operations, including production, manufacturing, delivery, shipment delays, customer needs, sales, and market share losses, negatively impacting the economic performance of the supply chain. For example, the ongoing pandemics of COVID-19 is considered the most severe disruption in the last decades, and during the pandemic, customers' demand was highly unpredictable, and suppliers could not meet their delivery obligations because of stringent rules; this has led companies to investigate on how industrial systems can improve resilience during disruptions.

In literature, resilience is recognized as a multidimensional construct, including a static and a dynamic perspective. (Acquaah et al., 2011) defined resilience as "a firm's ability to persist in significant changes in the business and economic environment and survive disruptions on an organizational level."In literature, supply chain resilience has received attention from numerous researchers. Some of them have proposed rigorous definitions. For example, (Christopher & Peck, 2004) defined supply chain resilience as: "the system's ability to return to its previous condition or move to a more desirable state after being disturbed."

More recently, researchers have started investigating the enabling factors for SC resilience development. In this regard, Industry 4.0 technologies play a determinant role, given their influence on supply chain operations

However, the existing literature is fragmented, leaving the understanding of the effect of I4.0 technologies on supply chain resilience not completely understood. To fill this research gap, we carry out a Systematic Literature Review addressing the following research question:

1. How I4.0 technologies favour the development of SC resilience?

2 RESEARCH METHODOLOGY

We carried out a Systematic Literature Review (SLR) to address our research questions. This was designed

[a] https://orcid.org/0000-0001-5152-0004
[b] https://orcid.org/0000-0002-1797-3699

Albeetar, S., Semeraro, C. and Massari, G.
Impacts of Industry 4.0 Technologies on Supply Chain Resilience.
DOI: 10.5220/0011588700003329
In *Proceedings of the 3rd International Conference on Innovative Intelligent Industrial Production and Logistics (IN4PL 2022)*, pages 153-160
ISBN: 978-989-758-612-5; ISSN: 2184-9285

consistently with previous studies (Colicchia & Strozzi, 2012). In the following, we describe the process of material collection and material refinement.

2.1 Material Collection

This first process is devoted to selecting databases and keywords to find the articles. There are, arguably, three major abstract and citation databases: Google Scholar, Scopus, and the Web of Science. Meanwhile, Scopus has broader coverage than the Web of Science, but the latter provides access to older sources (Farooque et al., 2019). Since we are investigating a recent phenomenon, accessing older sources offered by the Web of Science database is not an advantage. We, therefore, focused on Scopus. The data were collected in March 2022 using search criteria in the article title, abstract, and keywords of peer-reviewed articles (journal articles, chapters, and books). The search criteria were defined as the combination of the keywords related to Industry 4.0 technologies (see Table 1) with those regarding supply chain resilience context ("resilience") AND ("industry 4.0" OR "i4.0" OR "digital technolog*"). After excluding duplicate publications, we collected 277 records, including 217 journal articles and 60 reviews.

Table 1: List of keywords used for literature search.

Industry 4.0 Technology	Keywords
Internet of Things	IoT, Internet of Things
Cloud Computing	CC, Cloud Computing
Big Data Analytics	BDA, Big Data
Blockchain	Blockchain
Artificial Intelligence	AI, Artificial Intelligence
Cyber-physical system	CPSs, Cyber-Physical Systems
Additive Manufacturing	AM, 3D printing, Additive Manufacturing

2.2 Material Refinement

Refinement is a rigorous approach to analysing and evaluating the selected research articles to exclude those not explicitly addressing our research purpose. We refine the collected articles by meticulously analysing their titles and abstracts and then their full-length text. After reading titles and abstracts, 185 records were considered out of topic and filtered based on specific exclusion criteria. Thus, we collected 24 documents. In the following, we present the results of the content analysis.

3 THEORETICAL BACKGROUND

3.1 Supply Chain Resilience

The term resilience is developed and used in many areas such as engineering, ecology, environmental science, social, management, economics, and organisational science (Morisse & Prigge, 2017). Studies on supply chain resilience conceptualize it as the supply chain's ability to anticipate and respond to interruptions, recover quickly and cost-effectively, and advance to a post-disruption state better than before is the supply chain resilience; or even as the ability of a supply chain to decrease the possibility of facing unpredicted disruptions, resist disruptions by maintaining control over structures and functions, and recover and respond by putting in place quick and efficient reactive plans to deal with the disruption and return the supply chain to a stable state of operations.

Disruptions can result in a loss of market share, financial loss, reputational damage, a drop in shareholder value, or losing market opportunities (Morisse & Prigge, 2017). Disruption events are low-probability, high-impact occurrences that vary in type, scale, and nature, are intermittent and irregular to identify, assess, and anticipate adequately, and may have short or long-term negative consequences (Dolgui et al., 2018).

Thus, developing resilient supply chains represents an imperative. Given its relevance, scholars have investigated it widely. Rigorous, however non-convergent, definitions have been provided. While some of them point out the ability to "return to its previous condition or move to a more desirable state after being disturbed" (Christopher & Peck, 2004), others focused on that to "anticipate and respond to unexpected events and recover from unexpected events by keeping processes connected and under control of structure and function at the needed level". (Bhamra et al., 2011) defined resilience from a static perspective as "resilience is related to the system's ability to absorb disturbance and return back to the original normal state maintaining its core functions when shocked". Instead (Carvalho et al., 2012) defined resilience from a dynamic perspective as "resilience is viewed as the ability to adapt to a disturbance by moving towards the original but even new, more favorable equilibrium states". The development of supply chain resilience has been explained as occurring during specific phases. (Hohenstein et al., 2016) argued on the existence of four phases: readiness, response, recovery, and growth. Readiness refers to all pre-disruption steps that can be taken to lower the likelihood of disruption and absorb its harmful consequences. The response and recovery phases refer to post-disaster activities that aim to manage limited resources efficiently and effectively when responding to damage caused by disasters. The response includes countermeasures performed immediately after the supply chain disruption is detected or experienced. The speed must be prioritised at this stage to avoid negative consequences for the SC. The recovery phase refers to post-disaster activities which aim to manage limited resources efficiently and effectively when responding to damages caused by disasters; it targets restoring the SC's performance level. Finally, Growth measures are to improve SC performance over the pre-disruption condition. Most research concentrate on the ready and response stages, which differs from past research in specific ways.

3.2 The Supply Chain Resilience Drivers

The most studied drivers of supply chain resilience include agility, visibility, flexibility, and collaboration (Bode, 2016).

Agility is one of the most important drivers in supply chain resilience. Supply chain agility refers to an organisation's readiness and speed to respond to change and return to normal situation as quickly as possible (Hohenstein et al., 2016). Supply chain agility refers to the ability of the supply chain to quickly adapt the network structure and operations policies to the customer's dynamic and unpredictable requirements (Dubey et al., 2018). A company's ability to implement demand sensing by integrating information into a company philosophy helps improve supply chain agility (Hohenstein et al., 2016). Supply chain agility in a company's capacity to deliver products or services quickly benefits supply chain resilience.

Visibility tracks the identity, location, and status of entities passing through the supply chain and captures them in timely messages, along with the scheduled dates and times of these events. Demand visibility refers to information relating to the customers' dynamic requirements. Upstream and downstream inventories, demand and supply situations, and production and purchase schedules have also been called supply chain visibility.

Flexibility is the ability of the supply chain to adopt the change in the environments and stakeholders with minimal effort and time. Scholars claimed that flexibility, as a component of supply chain resilience, defines a ' 'company's ability to respond to market changes, even though such external influence is beyond the supply chain ecosystem's immediate scope and control. According to the literature, flexibility in terms of transportation, sourcing, labour arrangements, and postponement could all help build resilient supply chains (Pettit et al., 2013). According to (Pettit et al., 2013), flexibility improves rapid adaption during disruption conditions and makes the supply chain more resilient. Supply chains with less sourcing and order fulfilment flexibility are more sensitive to disruptions and less resilient.

Collaboration is essential for developing resilient supply chains (Pettit et al., 2013). Although experts agree that collaboration can improve supply chain resilience, it is unclear how it affects it (Hosseini et al., 2019). The ability of two or more autonomous firms to collaborate in planning and executing supply chain activities to meet shared objectives is referred to as collaboration in the supply. Collaboration allows partners to build synergies, ease cooperative planning, and stimulate real-time information exchange, which helps supply chains to prepare, respond, and recover from supply chain disruptions and reduce the impact of disruption on the supply chains.

3.3 Enabling Factors for Supply Chain Resilience: Industry 4.0 Technologies

Industry 4.0 support companies in digitalising manufacturing processes, enabling the communication between products and their business environments in different supply chain sectors, such as manufacturing, warehousing, inventory, logistics, delivery, and retailing. I4.0 technologies in the supply chain can record real-time data, which helps improve the supply chain's visibility and information sharing (Semeraro et al., 2019)(Ralston & Blackhurst, 2020). Real-time information enables autonomous decisions throughout the supply chain to best satisfy demand, including predictive analysis of the future demand predictions. Digitalization is pushing all the involved supply chain firms to digitalize their internal processes, operations, and relationships with partners through the implementation and integration of digital technologies (DTs). Thus, a traditional supply chain turns into an intelligent network of smart things, e.g., humans, products, and machines, supported mainly by artificial intelligence (AI), the Internet of Things (IoT), cyber-physical systems (CPSs), big data analytics (BDA), blockchain (BT), additive Manufacturing (AM).

These and other DTs make information available throughout the whole chain with enormous benefits for all the involved actors. According to the Master Expert of McKinsey & Company, Knut Alicke, digital supply chains benefit from the increased agility, flexibility, modularity, efficiency, and inter-firm collaboration derived from the implementation of DTs. AI enable more accurate demand forecasts through predictive analytics of Big Data, both internal (e.g., demand, machine status) and external (e.g., market trends, weather, school vacations, construction indices). A more accurate forecast of demand volume reduces the delivery time and lead time, avoiding problems of under or over-stocking. It allows following high-customization customer-based requirements. Real-time monitoring and planning make the entire chain more flexible and reactive to changing demand or supply operating conditions. Using advanced manufacturing systems, materials (e.g., pallets, boxes, single pieces) can be processed (e.g., received, unloaded, packed, shipped) automatically and flexibly. Cloud manufacturing technologies support customers, suppliers, and buying companies through shared logistic infrastructure partners can decide to tackle supply chain tasks together to save admin costs, leverage best practices, and learn from each other, thus improving inter-firm collaboration among supply chain partners.

Different studies confirm the positive effect of DTs on supply chain operations. Big Data positively affects supply chain and organizational performance (Dubey et al., 2018). It can influence the production network by promoting operational brilliance, cost reserves, and consumer loyalty. Supply chain leaders can use BD to improve their organizations' relationships with customers and suppliers and increase replenishment through improved inventory management. Big Data is useful in terms of helping managers to understand supplier performance. Big Data provides better forecasts, increases supply chain visibility, and strong supply chain relationships (Dolgui et al., 2018). Big Data in production planning and control is developing. Big Data is useful technology for the supply chain, especially for demand forecasting, procurement, inventory, and reverse logistics.

Internet of Things (IoT) in supply chains helps build up warehouse operations' efficiency, reduce unnecessary processes, and increase inventory time. The Internet of Things (IoT) makes supply chain management more effective and efficient. For example, the IoT enables improvements in cost savings, inventory accuracy, and product tracking (Ben-Daya et al., 2019). The IoT can also improve products, services, customer experience, and safety.

Cloud computing (CC) is most important for logistics management, database management, and demand forecasting and planning. Adoption of CC would promote collaboration among supply chain members. It would improve resource and information sharing. It would also improve adaptability to changes in demand (Manuel Maqueira et al., 2019).

Cyber-physical systems (CPSs) are the basis of I4.0 because they enable the digital integration of physical processes through integrated computers and networks to monitor and control these physical processes. In this context, these systems can create intelligent industries. CPSs contributes to optimizing inventory and production control.

Blockchain technology is leading to a new way of thinking about supply chain management. Blockchain is already helping to transform traditional business models and create new opportunities across the supply chain. Blockchain technology allows data to be tracked and shared more quickly, and adaptability can be provided instantly. Companies can conduct real-time exchanges via a blockchain-powered inventory network. BT (Bitcoin) takes a critical role as it tends to counter security breaches while improving supply chain availability. BT is hack-proof and carefully designed to ensure automatic traceability. Blockchain technology improves the tracking of goods and passengers, from their origin to overall supply chain management. It helps eliminate disclosure and accountability issues. Advanced manufacturing, particularly 3D printing, is being used to produce technical prototypes.

Advanced manufacturing, especially 3D printing, is used to produce engineering prototypes. It can massively customize goods on a large scale. 3DP helps reduce excessive inventory. 3DP's flexibility can reduce the number of suppliers and increase product quality. Similarly, product variety, shorter lead times, efficiency, and better inventory control can be achieved (Ivanov et al., 2019a). Augmented reality (AR) refers to the overlay of PC reproduction models with the physical design of a current environment. AR improves the effectiveness of current supply chain processes. Most normal types of AR incorporate some sort of glassy and visual representation that a carrier can utilise during the time of expanding profitability and execution. Expanded reality is utilised to give a sense of scene recognition when picking orders. Radio Frequency Identification (RFID) enables real-time identification, real-time material flow, and tracking, which increases data quality (Ivanov et al., 2019a). The great promise of RFID technology is to reduce costs and provide information that helps companies better understand, predict, and respond to customer demand.

Artificial intelligence (AI) techniques are being used for planning in cellular manufacturing systems. In addition, AI is being used in industry through machine vision and autonomous applications. Using predictive technologies to model future scenarios and develop a comprehensive understanding of supply chain interactions will improve business performance.

According to (Büyüközkan & Göçer, 2018) ten strategic objectives characterize a Digital Supply Chain. These are speed (ability to react quickly to demand), flexibility (agile reaction), global connectivity (internet-enabled SC), real-time inventory (continuous monitoring of stocks levels), intelligence (self-learning smart products), cost-effectiveness (use of technology to increase organisational performance), transparency (adjusting networks to changing scenarios), scalability (optimisation and duplication of processes), innovation (in pursue of competitiveness and excellence), proactivity (anticipating issues before occurrence).

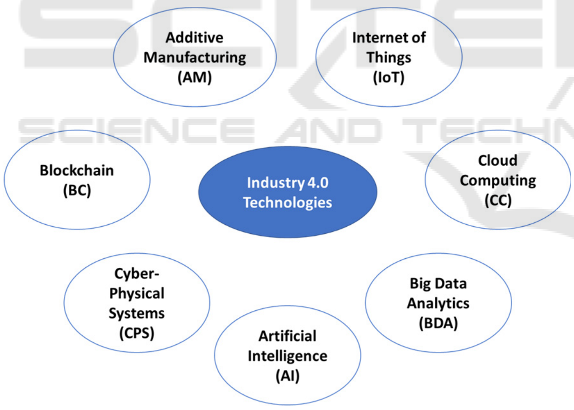

Figure 1: I4.0 technologies in Supply Chain Resilience.

4 RESULTS

Cloud Computing is decentralised nature enables easy data collection, storage, processing, and exchange among many entities, improving overall data accessibility and management within and across organisations. Therefore, Cloud Computing is generally considered to enhance the performance of SC (Queiroz et al., 2019). In a supply chain resilience context, Cloud Computing risk data can be collected, analysed, and interpreted more quickly, enabling more efficient planning of supply, transportation, and demand. Cloud Computing the program's effectiveness in improving supply chain's performance has been empirically demonstrated. For example, a study in the automotive industry found that cloud-based SMEs are more resilient than their non-cloud-based competitors.

IoT can help the supply chain resilience track items and determine key metrics such as temperature and pressure across the supply chain; this can improve the process and overall risk knowledge and strategies in the supply chain (Birkel & Hartmann, 2020). Specific application areas for Big Data in supply chain resilience include risk event prediction, proactive response planning, and reactive real-time control (Ralston & Blackhurst, 2020)(Ivanov & Dolgui, 2020). For example, Big Data can support the development and execution of continuity plans during periods of supply chain disruptions. In addition, Big Data can be combined with traditional simulation techniques to create digital supply chain twins (Ivanov & Dolgui, 2020). These models can help understand complex supply chain resilience problems, identify possible solutions, visualise dynamics, and test alternative scenarios.

Autonomous robots and vehicles play an essential role in Cyber-Physical Systems, as they can facilitate or even take over the work of personnel to reduce potential risks and errors from human labour, especially during a pandemic. As a specific supply chain resilience example, an automated system for detecting and transporting test samples from the assembly line to a laboratory mitigates potential quality risks more reliably and efficiently than human workers ever could (Ralston & Blackhurst, 2020)

By using Additive Manufacturing, potential sources of risk in the supply chain can be reduced, such as, the number of production steps, suppliers, and transportation links (Ivanov et al., 2019a).

In the context of supply chain, Blockchain can be used to verify the accuracy of the information and to track locations and ownership (Ivanov & Dolgui, 2020). Supply chain resilience can benefit significantly from these application areas, as blockchain improves open communication, coordination, and trust across organisational boundaries.

Most of the identified papers deal with Big Data solutions, which supports (Ivanov et al., 2019b) as Big Data is considered mature in research and industry. All other enabler technologies do not show a high number of contributions. Many researchers expect significant improvements in supply chain resilience from I4.0. (Ivanov et al., 2019a)(Ralston &

Blackhurst, 2020). This shows that research has yet to uncover the potential and detailed application areas of each I4.0 enabler technology in supply chain resilience.

4.1 Impacts of I4.0 Technologies on Agility Driver in Supply Chain

In this context, the Internet of Things perception capabilities are based on a range of identification and tracking technologies that allow for remote monitoring of physical things, increasing visibility. IoT applications and Cyber-Physical Systems significantly impact tracking and tracing the material flow and improving risk transparency in the supply chain. Tracking and tracing systems are used parallel with radio frequency identification to offer real-time information about process execution. The tracking and tracing systems can help at the recovery stage to monitor and predict disruptions. Also, the tracking systems are designed to detect disruptions or the threat of disruptions in supply chains as soon as possible, analyse disruptions, provide alerts about what disruptions have occurred or may occur, and develop management measures to restore supply chain operations. Big data is discussed in the context of digital supply chain twins; the data from different sources are processed and combined with simulation techniques to represent the real-world supply chain.

4.2 Impact of I4.0 Technologies on Visibility Driver in Supply Chain

Big Data helps improve market visibility through predictive analytic techniques, which leads to more reliable demand and sales forecasts. Artificial Intelligence can help achieve supply chain resilience by having access to real-time tracking of every ingredient that goes into a product and highly accurate inventory counts. Artificial Intelligence can help find supply routes and fulfilment processes to shorten delivery times. Also, Artificial Intelligence helps decision-makers use demand data to make more accurate demand forecasts. Blockchain can help supply and demand visibility through real-time data sharing. Adopting analytical models can transform raw data into valuable forecasts and optimised outcomes. As a result, practically all products in an IoT-enabled environment, including products, machinery, and devices, have sensors and are connected to the Internet; the advanced level of connectivity can lead to enhanced visibility and considerably improve supply chain resilience by enabling real-time access to information.

4.3 Impact of I4.0 Technologies on Flexibility Driver in Supply Chain

Flexibility is the only supply chain resilience driver that all I4.0 technologies support. Supply chain flexibility is the ability to rapidly change the process to achieve the same goals. I4.0 will allow the work and operation to be performed faster while changing any process, leading to improved lead times. Big Data can detect risks and possible disruption occurrences earlier, executing mitigation measures faster, leading to supply chain resilience. The Artificial Intelligence helps replace labour-intensive and time-consuming operations with automatic information processing and interpreting capabilities. Cloud computing enables flexibility by creating a reliable, real-time data platform that allows companies to assess supply chain inventory and accelerate and reroute as needed, and the faster access to data generally leads to better decisions during disruptions. Finally, Cyber-Physical Systems radically affect the supply chain and manufacturing processes and enable more responsive and flexible production.

4.4 Impact of I4.0 Technologies on Collaboration Driver in Supply Chain

Real-time information tracking using blockchain has the potential to change the way that the information is shared between supply chain partners. For instance, Internet of Things sensors can be used to send real-time data about storage and traffic conditions. The data is permanently stored on the blockchain and transmitted to other areas of the supply chain such as logistics and transport. This will allow firms to take action during disruptions. Big Data and Artificial Intelligence applications can use a massive amount of data generated from the supply chain operations to help build a resilient supply chain by sharing important data on risks and supply chain disruptions to all relevant supply chain members faster, the faster data access to supply chain members generally leads to better decision-making and performance advantages during disruptions. Cloud Computing can play an essential role in sharing and processing information, for example if a project needs multiple interactions from different entities in the supply chain, cloud computing can be used to give employees, managers and contractors access to the same files which will lead to easier information sharing. Information sharing can be enhanced by integrating detailed data gained from IoT devices. IoT's ability to collect real-time data increases communication in the supply chain and simplifies redistribution activities, allowing businesses to better manage supplier-buyer relationships during disruptions. Cyber-Physical Systems can help supply chains by improving communication and information sharing, resulting in more smooth and adaptable operations that lead to supply chain resilience. Cyber-Physical Systems for example, can offer a better knowledge of the requirements along the supply chain and improve collaboration and cooperation between them by providing a high level of integration and information exchange. As a result, supply chain decision-making and responsiveness may increase, resulting in enhanced product delivery and customer satisfaction.

Fig. 2 summarises the relationship between supply chain resilience drivers (Layer 1) and I4.0 technologies (Layer 2). The following paragraph summarise the impact of the I4.0 technologies on each driver and how they can be affected.

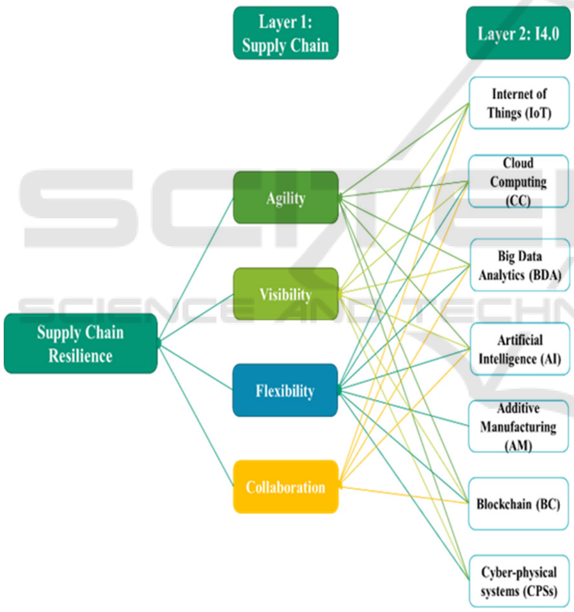

Figure 2: Impact of I4.0 Technologies on Supply Chain.

5 CONCLUSIONS AND FUTURE WORK

Disruptions in the supply chain are the most dangerous events, so one of the most important aspects is developing a resilient supply chain. Previous studies suggest that this can be addressed effectively using Industry 4.0 technologies because these can effectively influence the supply chain resilience drivers: agility, flexibility, visibility, and collaboration. I4.0 in supply chain resilience focuses on solutions supporting the first two supply chain resilience phases, the readiness and response phases. While solutions for recovery and growth phases are still limited, I4.0 will become a fundamental basis for improving supply chain resilience. There is no formalized knowledge that describes the relationship between I4.0 and supply chain resilience and what is the effect of I4.0 technologies on the Supply chain resilience drivers. For this reason, the paper analyses the impacts of the I4.0 technologies on supply chain resilience. Industry 4.0 technologies influence the organizational and operational practices to enhance supply chain resilience at each stage of the supply chain. For the future work, after concluding that there is no clear formalized knowledge that describes the relationship between I4.0 and supply chain resilience and what is the effect of I4.0 technologies on the supply chain resilience drivers, so the need for creating an ontology becomes important, so it can help the managerial levels in the supply chains in decision making during disruptions. After creating the ontology, it is planned to apply it to a case study and then evaluate the performance of the firm.

REFERENCES

Acquaah, M., Amoako-Gyampah, K., & Jayaram, J. (2011). Resilience in family and nonfamily firms: An examination of the relationships between manufacturing strategy, competitive strategy and firm performance. *International Journal of Production Research*, *49*(18), 5527–5544. https://doi.org/10.1080/00207543.2011.563834

Ben-Daya, M., Hassini, E., & Bahroun, Z. (2019). Internet of things and supply chain management: a literature review. *International Journal of Production Research*, *57*(15–16), 4719–4742. https://doi.org/10.1080/00207543.2017.1402140

Bhamra, R., Dani, S., & Burnard, K. (2011). Resilience: The concept, a literature review and future directions. *International Journal of Production Research*, *49*(18), 5375–5393. https://doi.org/10.1080/00207543.2011.563826

Birkel, H. S., & Hartmann, E. (2020). Internet of Things – the future of managing supply chain risks. *Supply Chain Management*, *25*(5), 535–548. https://doi.org/10.1108/SCM-09-2019-0356

Bode, C. (2016). Stages of Supply Chain Disruption Response : Direct , Constraining , and Mediating Factors for Impact Mitigation. *Decision Sciences*, *00*(0), 1–39.

Büyüközkan, G., & Göçer, F. (2018). Digital Supply Chain: Literature review and a proposed framework for future research. *Computers in Industry*, *97*, 157–177. https://doi.org/10.1016/j.compind.2018.02.010

Carvalho, H., Barroso, A. P., MacHado, V. H., Azevedo, S., & Cruz-Machado, V. (2012). Supply chain redesign for resilience using simulation. *Computers and Industrial Engineering*, *62*(1), 329–341. https://doi.org/10.1016/j.cie.2011.10.003

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

Colicchia, C., & Strozzi, F. (2012). Supply chain risk management: A new methodology for a systematic literature review. *Supply Chain Management*, *17*(4), 403–418. https://doi.org/10.1108/13598541211246558

Dolgui, A., Ivanov, D., & Sokolov, B. (2018). Ripple effect in the supply chain: an analysis and recent literature. *International Journal of Production Research*, *56*(1–2), 414–430. https://doi.org/10.1080/00207543.2017.1387680

Dubey, R., Altay, N., Gunasekaran, A., Blome, C., Papadopoulos, T., & Childe, S. J. (2018). Supply chain agility, adaptability and alignment: Empirical evidence from the Indian auto components industry. *International Journal of Operations and Production Management*, *38*(1), 129–148. https://doi.org/10.1108/IJOPM-04-2016-0173

Farooque, M., Zhang, A., Thürer, M., Qu, T., & Huisingh, D. (2019). Circular supply chain management: A definition and structured literature review. *Journal of Cleaner Production*, *228*(July), 882–900. https://doi.org/10.1016/j.jclepro.2019.04.303

Hohenstein, N.-O., Feisel, E., & Hartmann, E. (2016). Research on the phenomenon of supply chain resilience A systematic review and paths for further investigation. *International Journal of Physical Distribution & Logistics Management*, *46*(2), 153–176.

Hosseini, S., Ivanov, D., & Dolgui, A. (2019). Review of quantitative methods for supply chain resilience analysis. *Transportation Research Part E: Logistics and Transportation Review*, *125*(February), 285–307. https://doi.org/10.1016/j.tre.2019.03.001

Ivanov, D., & Dolgui, A. (2020). Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak. *International Journal of Production Research*, *58*(10), 2904–2915. https://doi.org/10.1080/00207543.2020.1750727

Ivanov, D., Dolgui, A., & Sokolov, B. (2019a). 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., Dolgui, A., & Sokolov, B. (2019b). 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

Manuel Maqueira, J., Moyano-Fuentes, J., & Bruque, S. (2019). Drivers and consequences of an innovative technology assimilation in the supply chain: cloud computing and supply chain integration. *International Journal of Production Research*, *57*(7), 2083–2103. https://doi.org/10.1080/00207543.2018.1530473

Morisse, M., & Prigge, C. (2017). Design of a business resilience model for industry 4.0 manufacturers. *AMCIS 2017 - America's Conference on Information Systems: A Tradition of Innovation*, *2017-Augus*, 1–10.

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

Queiroz, M. M., Pereira, S. C. F., Telles, R., & Machado, M. C. (2019). Industry 4.0 and digital supply chain capabilities: A framework for understanding digitalisation challenges and opportunities. *Benchmarking*, *28*(5), 1761–1782. https://doi.org/10.1108/BIJ-12-2018-0435

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

Semeraro, C., Lezoche, M., Panetto, H., Dassisti, M., & Cafagna, S. (2019). Data-Driven Pattern-Based Constructs Definition for the Digital Transformation Modelling of Collaborative Networked Manufacturing Enterprises. *IFIP Advances in Information and Communication Technology*, *568*, 507–515. https://doi.org/10.1007/978-3-030-28464-0_44

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 and Industrial Engineering*, *158*(June), 107452. https://doi.org/10.1016/j.cie.2021.107452