Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 91 (2020) 752–757

www.elsevier.com/locate/procedia

30th CIRP Design 2020 (CIRP Design 2020)

Achieving resilience in the supply chain by applying IoT technology

Moayad Al-Talib*[a], Wasen Y. Melhem [b] , Anthony I. Anosike [a] , Jose Arturo Garza Reyes [a], Simon Peter Nadeem [a], Anil kumar [a]

[a] *Centre for Supply Chain Improvement, University of Derby, Derby, UK, DE22 1GB*

[b] *Computer Information Systems Department, Yarmouk university, Irbid, Jordan, 21163*

* Corresponding author. Tel.: +447472030777; E-mail address: M.al-talib@Derby.ac.uk

Abstract

In the past few decades, competition has increased between organizations as a result of globalization and fast development in IT. Companies these days are continuously looking to expand their market geographically to attract new customers. With that in mind, the main concern of companies is to achieve their customers' requirements, which makes the supply chain (SC) longer and more complex. This leads to increased difficulty in managing the SC along with controlling risks and disruptions in SC. Such as loss of a critical supplier, a fire accident in the production facility, or an act of terrorism.

To deal with these risks, SC must be designed to provide an efficient and effective response, keep its process working and be capable of recovering to their original state after disruptive events, this is considered as the core of supply chain resilience (SCRes). Furthermore, companies that design their SC with capabilities to react quickly to any disruptions in its process have the opportunity to become more stabilized and acquire an improved position in the market.

Researchers have been exploring ways to acquire supply chain resilience, such as encouraging and improving collaboration between SC partners or by increasing the organization's visibility through monitoring SC events and patterns.

Studies have shown that IT has a role in improving SCRes, such as information-sharing systems to promote collaboration and visibility tactics. However, recent research trends are exploring new and emerging technologies like the Internet of Things (IoT). Despite the growing interest in IoT, minimal research has been carried out for its application in SCRes. Research in this direction is necessary to explore opportunities provided by IoT to redesign SC which in turn reinforces flexibility of supply chains and aspects of analysis of the product quality and how it could enable companies to improve their SCRes. This study is directly focused to identify and highlight this gap.

Peer-review under responsibility of the scientific committee of the CIRP BioManufacturing Conference 2019.

Keywords: Supply chains, Supply chain resilience, IoT, Internet of Things,

1. Introduction

With the wide advances in technology, it has become mandatory for organizations to acquire a competitive advantage in the market through incorporating information technology, IoT, big data and cloud computing technologies across the supply chain. Internet of things (IoT) delivers new opportunities to mitigate risks, manage complexity and provide tangible business benefits through increasing transparency and flexibility across the supply chain (SC).

Supply chain resilience (SCRes) is "The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function"[1].

The connectedness and control needed across the SC to adapt and be prepared in the case of disruptions can be captured by the capabilities of the IoT, Smart technologies allow one to remotely monitor and control the location and conditions of shipments and products from production to the end customer[2].

Furthermore, collaboration and visibility are straightforward processes with real time connectivity. Scholars agree that

Peer-review under responsibility of the scientific committee of the CIRP BioManufacturing Conference 2019
10.1016/j.procir.2020.02.231

collaboration is one of the key elements of a resilient SC where two or more firms work effectively together, planning and executing supply chain operations toward common goals [3],[4], [5].

Another approach to improve SCRes is by increasing the organization's visibility through monitoring SC events. Supply chain visibility and collaboration depend on information sharing between its members[4], [6].

Rice Jr and Caniato (2003) mentioned that resilience can be enhanced by making the supply chain structure more flexible [7]. Other approaches include controlling supply chain processes by implementing policies that prevent disruptions, such as implementing lean production, six sigma practices, develop products with appropriate levels of quality and strong corporate culture [8].

Nevertheless, there is a lack of research found showing the association between IoT and SCRes[9], [10]. This research aims to discuss the potential of IoT on SCRes, and how incorporating IoT can overcome obstacles by introducing technologies such as RFID and sensors. The effects of IoT on SCRes will be explored by concentrating on the main characteristics of SCRes.

2. Formulating the Scope of the Search

Resilience is the way supply chains deal with impending vulnerabilities and/or potential disruptions. IoT is an emerging technology which has huge potential to enable organisation to pro-actively manage supply chain resilience.

In this scope the following research queries have been identified to explore the existing literature:

- Exploring how the SCRes and IoT concepts have been industrialized in the literature to identify the current gap and potential research possibilities with its implications to the field of supply chain resilience?
- How SCRes are measured?
- Identifying the key elements in these two concepts and how they are related according to the existing literature?
- Exploring the potential impacts, benefits, challenges and considerations from implementing IoT in the field of SCRes?

During the search, keywords were used, such as "Supply chain resilience" to search for journal articles/conference papers and words like "IoT" within the journal articles to show the IT side in the papers. This paper used several defined keywords as search criteria. The keywords consisted of the phrase "supply chain" combined with the following keywords: "Resilience," "vulnerability, "Risk,"and "agility" with other keywords from the IT fields such as "Information technology," "IT," "Technological capability,"ICT," Information and Communication technology ,""Internet of things," "IoT," "RFID," "Radio-frequency identification," "Big data,".

Figure 1 displays the percentage of research regarding topics in both supply chain fields as well as information technology. The lack of research on SCRes is evident with only 14% articles. Furthermore, despite the importance of IoT and smart technology in supply chains, there is further research needed in this field with only 11% in IoT articles. However, this research found an increasing trend in the number of published journal articles in recent years, almost 88% of the selected papers were published from 2010 to 2018[11], [12],[13]. This proves that the significance and growing interest in this research topic highlights the need to expand research in this area. Only one article discusses the association between SCRes and IoT and shows its importance. This demonstrates that further research on this topic is required.

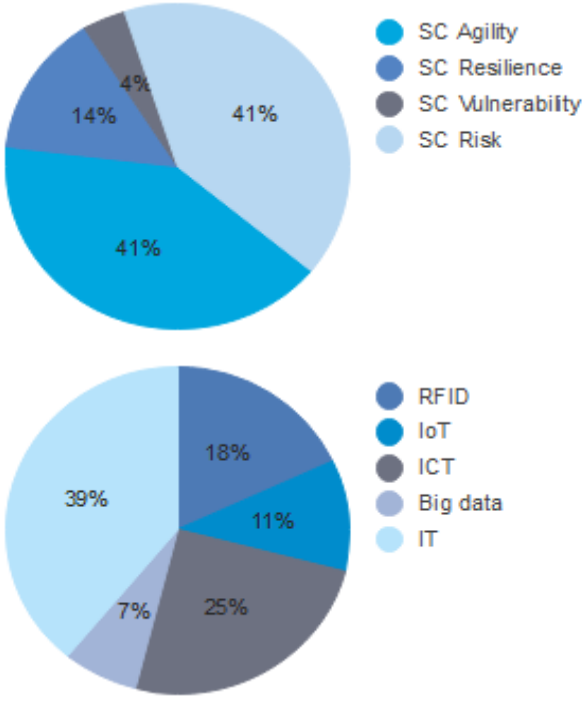

Fig. 1. Percentage of journal articles/conferences based on keywords

3. IoT and supply chain resilience

Many researchers have studied attributes of supply chain resilience. Soni, (2011) has discussed the characteristics of SCRes in terms of: flexibility, adaptability, collaboration, visibility and sustainability. These attributes enable competitive gain as well as reduce the level of disruption in supply chains[14].

In this paper, the effect of IoT on supply chain resilience will be discussed based on the supply chain resilience attributes shown in Figure 2.

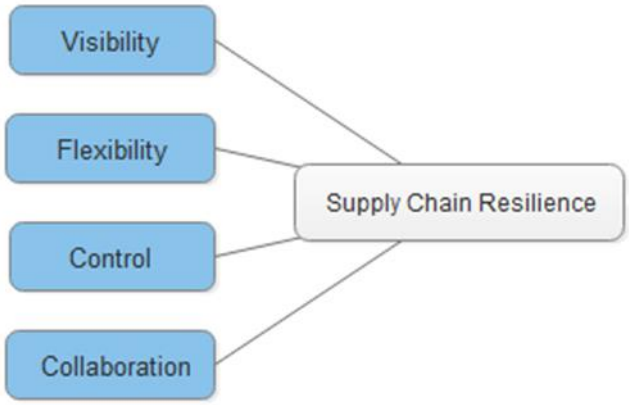

Fig 2. Supply chain resilience attributes chain resilience attributes

Challenges of the traditional supply chains directly affect the attributes of SCRes shown in figure 2 that are essential for a supply chain that can manage change and reduce disruptions. Complexity, increased costs, inaccuracies, and increased risks are issue that faced traditional supply chains[15][16].

Before introducing IoT into the SC, data and information were shared to a single actor only, this reduced transparency, as opposed to the smart SC which enables collaboration with all the needed actors simultaneously. Visibility was also an issue because of the lack of real time data and information that resulted in errors, inaccuracies and information distortion across the supply chains [17].

Complexity and uncertainty entail many problems in the past SC such as mistakes in delivery and new pick up orders that resulted in wasted time and costs. The implementation of IoT technologies aims to change the business model of traditional supply chains, this will lead to redesigning the past business models.

Introducing IoT into the supply chain functions will reduce costs, complexity and inaccuracies along the chain. Visibility in supply chains entails information sharing and transparency in a timely manner. This increases confidence in the supply chain. Therefore, risks are minimized due to effective response. Collaboration requires information to be accessed across concerned partners. It is vital in SCRes to ensure reduced ambiguity and event readiness as SCRes is network wide. Flexibility guarantees that disruptions can be dealt with without affecting the supply chain negatively. Flexibility includes both velocity and speed of handling functions in the supply chain[9].

The most recognized definitions in SCRes have included aspects of control or connectedness Ponis and Koronis, (2012), Ponomarov and Holcomb (2009), Reich (2006) because control has a direct effect on reducing the power of disruption or catastrophic events in supply chain which is the essence of SCRes[1].

IoT can be introduced to add real time aspects and improve functions of supply chain resilience. Data mining, the cloud, analysis and connectivity are among the methods that exceed the traditional SC in controlling and tracking supply chain functions through the use of sensors and tags[18].

Real time identification, traceability and tracking are considered to be the quickest methods in which data and information are transferred across departments and delivered to supply chain actors to aid decision making in emergencies or disruptions [19], [20].

In this paper, Supply chain resilience will be explored by targeting four important components: visibility, flexibility, collaboration and control.

3.1 Visibility

To start with, IoT gives supply chain visibility the ability of tracking products, deliveries and services. Time can be used more efficiently by reducing labor times and enhancing communication. Real time visibility may in turn increase productivity and consumers happiness. McFarlane and Sheffi Developed an Auto ID method that has enhanced the visibility aspect of supply chains where the status of shipments can be tracked meticulously throughout the lifecycle of the product. However, the main issues facing technological identification in the supply chain were also discussed. First, the requirement of on demand access from huge databases may compromise the trust of data. Second, the accuracy of data sets demands on identification tags and readers. Third, electromagnetic interference with large scale Auto ID networks[21].

To solve issues of privacy and security in RFID tags, researchers have focused on the aspects of RFID in IoT[22],[23],[24]. An important issue posed by Majeed and Rupasinghe, (2017) is the cost of RFID tags. Where the importance of applying visibility through IoT should be manipulated in every supply chain. However, the expense should be lowered to enable businesses to be able to compete in the market[22].

In an effort to increase the trust in extracted data, Yue, (2016) applied rule mining to ensure continuous quality in the data transmitted in food supply chains with IoT. The use of data mining ensures that past mistakes aren't repeated. This research shows that extraction of required data from huge amounts of data needs time which may result in mistakes[25].

3.2 Flexibility

Second aspect of supply chain resilience is flexibility. This is vital and intertwined with resilient supply chain management as

it takes into account aspects of the system, product and process such as the ability to reconfigure supply chains as required by customers or to customize the information architecture as required. With increased connectivity and integration, the flexibility of supply chains is bound to increase and simplify the process of collecting and exchanging information between concerned parties.

Automated and real time supply chains allow more flexibility to act and react quickly by introducing smart supply chains and self-thinking supply chains[26]. However, there is a lack in simulation models and architecture that explain the smart supply chain flexibility[9].

Korpela, (2017) discusses how digital supply chains have direct effects on flexibility, such as smart contracts that are employed to allow programmable transactions as well as machine-to-machine communication in Internet of Things[27].

Closs, (2005) Notes that enhancing the flexibility aspect of supply chains through connectivity can have a positive effect on the supply chain performance as a whole. This study tested information connectivity effects on supply chain flexibility through performance measures like quality of products, responsiveness, delivery and productivity[28].

Zhou, (2018) proposed a solution for RFID systems to handle the issues of flexibility in current RFID authentication issues in the health care arena. Flexibility as well as collaboration aspects of supply chains can be attained by tackling issues of RFID protocols. This allows an enhanced communication method in work settings and handles technological constraints in health care. This research also classifies the methods that should aid the efficiency of a supply management with information technology. Hence, IoT gives supply chains the ability to complete tasks, and recover from disruptions rapidly by efficiently utilizing the information collected and modelled [23].

3.3 Collaboration

Third aspect of supply chain resilience is collaboration. The speed of sharing information in real time between partners and managers is the key to successful supply chain collaboration. In turn, effective collaboration will reduce the possibility for uncertainties and unexpected circumstances [9].

Despite the countless benefits of the interconnectedness of sensors and collaboration among departments. Collaboration with IoT may rise disruption, privacy and safety concerns especially in health care cases. for example, among a web of sensors, a single mistake may prove fatal for a patient [29].

Lou, (2011) describes functions of supply chain collaboration with IoT into purchasing, fabricate, and transport sectors. Purchasing domain aims to get real-time data on products. In the fabricate sector the main focus is monitoring purposes and finally, the transport section relies on locating the product [30].

3.4 Control

The last aspect of supply chain resilience is control. IoT and real time methods enable enhanced control, planning, quality assessing and decoupling of information characteristics as of supply chains. Including IoT into supply chain control can mitigate the need for the availability of human monitoring supply chain functions physically. Nevertheless, virtual monitoring exceeds the information collected by humans such as sensor information and historical and predicted aspects of items[31].

To minimize costs and increase productivity real time control is a must. Control methods such as smart grid may be able to improve processes and predict outcomes[29].Moreover, costs of supply chain control can be mitigated by applying IoT due to the information IoT can provide for inventory control, Wang, (2018) developed a model by incorporating an immune genetic algorithm to handle the time cost of delayed transportation[32]. A tool was developed to reduce costs and food waste by simulating supply chain functions in the food industry, to find problems or monitoring profits and real time tracking and control [33].

Yang, (2015) developed an inexpensive RFID model to allow tracking of IoT devices in supply chains using one-to-one mapping, possible attacks can be spotted and may use several methods at once that resolve security and privacy challenges for IoT supply chain[24].

4. Discussion

Data availability is not the biggest issue in supply chains. The real issue is about successfully handling and analyzing data to gain real insight into decision making [20]. Redesigning supply chains using IoT technologies offer SCRes many abilities to overcome the weaknesses in traditional supply chain management such as lack of flexibility or difficulty in the decision-making process. The redesign of outdated methods in supply chain to incorporate smart technologies also allows for enhanced sustainability and simplifies the product quality analysis [34].

Sensors and machine learning approaches provide SCRes predictive capabilities to mitigate risks as the supply chain acquires self-learning capabilities, or reducing the effects of risks in cases of a fire or accidents in production by sending warning signals, then quickly handling the situation with the assistance of real time monitoring and effective flow of information.

The application of smart technologies can affect the supply chain from various dimensions to guarantee a resilient chain.

To start with, IoT enhances aspects of supply chain visibility through advanced transparency across the SC, it enables accuracy and reliability of transmitted data. Thus, supports the decision-making process and trust from consumers and partners increases. Second, Smart technologies can advance the supply chain flexibility by providing the chain with constancy and capability to tolerate accidents by the application of programmable processes such as smart scheduling methods.

Third, Machine to human collaboration is the main aim of supply chain collaboration. Connectivity and automation of collaboration activities enables synchronization among partners through IoT enabled productivity and delivery.

Fourth, Information gathered from sensors in real time monitoring and control delivers intelligent control in supply chain. This will ensure security throughout the chain. Moreover, improved management of products and services increase the ability to track resources in real time. The accuracy in inventory control enhance SC agility by speeding up information flow processes. Therefore, IoT delivers promising potential to address supply chain resilience, speed to handle errors and strong analysis on big data. Figure 3 displays the effect of IoT on SCRes in terms of visibility, flexibility, collaboration and control.

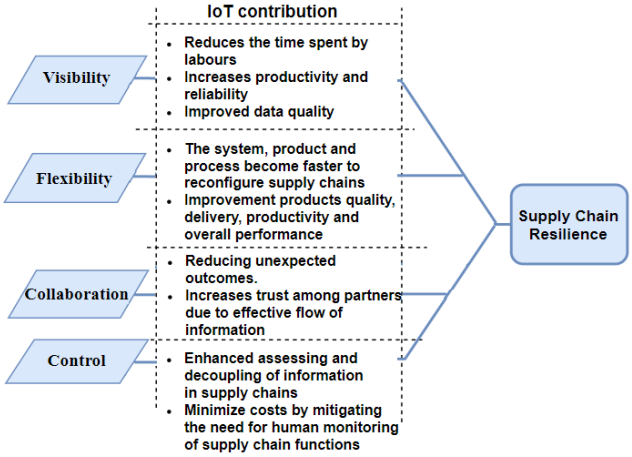

Fig. 3. IoT contributions in supply chain resilience

5. Conclusion

In this research, we presented a framework for supply chain resilience based on IoT technologies. Resilience is compulsory in supply chains to undergo short term processes and become more robust in the long run. We focused on four important aspects of resilient supply chains: visibility, flexibility, collaboration and control. Due to the lack of research discussing the effect IoT has on SCRes, our research has focused on the use of smart devices and IoT technologies in redesigning traditional supply chains through four dimensions that ensure a resilient SC. Functions in supply chains such as tracking and tracing of products and thorough information flow across the chain can become more effective by introducing smart technologies. IoT promises timely and accurate information throughout the supply chain with data and information perceived in real time. However, few articles have been found in the topic of supply chain resilience with IT background. It's clear that there are several directions and opportunities for further research in the area of resilience and in the supply chain when connecting it with IT field in general.

Despite the growing interest towards IoT, minimal researches have been carried out for its application in supply chain resilience [9],[10] and based upon the literature review discussed earlier, the problems/gaps can be summarized as follows:

- Huge databases may compromise the trust of data.
- The accuracy of data sets demands on identification tags and readers.
- Electromagnetic interference with large scale Auto ID networks.
- Privacy and security in RFID tags.
- Lack in simulation models and architecture that explain the smart supply chain flexibility metrics and measures in IoT.
- Privacy and safety concerns in information sharing.

References

[1] S. Y. Ponomarov and M. C. Holcomb, "Understanding the concept of supply chain resilience," *Int. J. Logist. Manag.*, vol. 20, no. 1, pp. 124–143, 2009.

[2] C. N. Verdouw, A. J. M. Beulens, and J. G. A. J. van der Vorst, "Virtualisation of floricultural supply chains: A review from an internet of things perspective," *Comput. Electron. Agric.*, vol. 99, no. November, pp. 160–175, 2013.

[3] K. Scholten and S. Schilder, "The role of collaboration in supply chain resilience," *Supply Chain Manag. An Int. J.*, vol. 20, no. 4, pp. 471–484, 2015.

[4] M. Christopher and H. Peck, "BUILDING THE RESILIENT SUPPLY CHAIN," *Int. J. Logist. Manag.*, vol. 15, no. 2, pp. 1–13, 2004.

[5] R. Ireland and R. Bruce, "CPFR: Only the Beginning of Collaboration," *Supply Chain Management Review*, pp. 80–88, 2000.

[6] M. N. Faisal, D. K. Banwet, and Ravi Shankar, "Supply chain risk mitigation: modeling the enablers," *Bus. Process Manag. J.*, vol. 12, no. 4, pp. 535–552, 2006.

[7] J. B. Rice Jr and F. Caniato, "Building a secure and resilient supply network," *Supply Chain Manag. Rev.*, vol. 7, no. 5, pp. 22–30, 2003.

[8] P. Mensah and Y. Merkuryev, "Developing a Resilient Supply Chain," *Procedia - Social and Behavioral Sciences*, vol. 110. pp. 309–319, 2014.

[9] A. Gunasekaran, N. Subramanian, and S. Rahman, "Supply chain resilience: Role of complexities and strategies," *Int. J. Prod. Res.*, vol. 53, no. 22, pp. 6809–

6819, 2015.
[10] J. S. L. Lam and X. Bai, "A quality function deployment approach to improve maritime supply chain resilience," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 92, no. August, pp. 16–27, 2016.
[11] A. Ali, A. Mahfouz, and A. Arisha, "Analysing supply chain resilience: integrating the constructs in a concept mapping framework via a systematic literature review," *Supply Chain Manag. An Int. J.*, vol. 22, no. 1, pp. 16–39, 2017.
[12] R. C. Pereira, C. Martin, and L. A. Silva Da, "Achieving supply chain resilience: the role of procurement," *Supply Chain Manag. An Int. J.*, vol. 19, no. 5/6, pp. 626–642, 2014.
[13] M. Kamalahmadi and M. M. Parast, "A review of the literature on the principles of enterprise and supply chain resilience: Major findings and directions for future research," *International Journal of Production Economics*, vol. 171. pp. 116–133, 2016.
[14] U. Soni and V. Jain, "Minimizing the vulnerabilities of supply chain: A new framework for enhancing the resilience," in *IEEE International Conference on Industrial Engineering and Engineering Management*, 2011, pp. 933–939.
[15] M. Abdel-basset, G. Manogaran, and M. Mohamed, "Internet of Things (IoT) and its impact on supply chain : A framework for building smart , secure and efficient systems," *Futur. Gener. Comput. Syst.*, vol. 86, no. September, pp. 614–628, 2018.
[16] M. A. Adeseun, A. I. Anosike, J. A. Garza Reyes, and M. Al-Talib, "Supply Chain Risk Perception: Understanding the Gap Between Theory and Practice," *IFAC-PapersOnLine*, vol. 51, no. 11, pp. 1701–1706, 2018.
[17] N.-O. Hohenstein, E. Feisel, E. Hartmann, and L. Giunipero, "Research on the phenomenon of supply chain resilience: A systematic review and paths for further investigation," *International Journal of Physical Distribution & Logistics Management*, vol. 45, no. 1/2. pp. 90–117, 2015.
[18] J. Dweekat, A. J., Hwang, G., & Park, "A supply chain performance measurement approach using the internet of things: toward more practical SCPMS," *ndustrial Manag. Data Syst.*, vol. 117, no. 2, pp. 267–286, 2017.
[19] D. R. G. Z, A. Nait-sidi-moh, D. Durand, and J. Fortin, "Using Internet of Things technologies for a collaborative supply chain : Application to tracking of pallets and containers," *Procedia - Procedia Comput. Sci.*, vol. 56, no. Msis, pp. 550–557, 2015.
[20] M. Ben-daya, E. Hassini, and Z. Bahroun, "Internet of things and supply chain management : a literature review," *Int. J. Prod. Res.*, vol. 7543, no. November, pp. 1–23, 2017.
[21] D. Mcfarlane and Y. Sheffi, "The Impact of Automatic Identification on Supply Chain Operations," *Int. J. Logist. Manag.*, vol. 1, no. 14, pp. 1–27, 2003.
[22] M. A. A. Majeed and T. D. Rupasinghe, "Internet of Things (IoT) Embedded Future Supply Chains for Industry 4 . 0 : An Assessment from an ERP-based Fashion Apparel and Footwear Industry," *Int. J. Supply Chain Manag.*, vol. 6, no. 1, pp. 25–40, 2017.
[23] W. Zhou and S. Piramuthu, "IoT security perspective of a flexible healthcare supply chain IoT security perspective of a flexible healthcare supply chain," *Inf. Technol. Manag.*, vol. 19, no. 3, pp. 141–153, 2018.
[24] K. Yang, D. Forte, and M. M. Tehranipoor, "Protecting Endpoint Devices in IoT Supply Chain," in *IEEE/ACM International Conference on Computer-Aided Design*, 2015, pp. 351–356.
[25] H. Yue, "Food safety pre-warning system based on data mining for a sustainable food supply chain," *Food Control*, vol. 73, no. March, pp. 223–229, 2016.
[26] A. Calatayud, "The Connected Supply Chain: Enhancing Risk Management in a Changing World," in *Inter-American Development Bank.*, 2017, no. March.
[27] K. Korpela and T. Dahlberg, "Digital Supply Chain Transformation toward Blockchain Integration," in *In proceedings of the 50th Hawaii international conference on system sciences*, 2017, pp. 4182–4191.
[28] D. J. Closs, M. Swink, and A. Nair, "The role of information connectivity in making flexible logistics programs successful," *Int. J. Phys. Distrib. Logist. Manag.*, vol. 35, no. 4, pp. 258–277, 2005.
[29] I. Lee and K. Lee, "The Internet of Things (IoT): Applications , investments , and challenges for enterprises," *Bus. Horiz.*, vol. 58, no. 4, pp. 431–440, 2015.
[30] L. Ping, Q. Liu, Z. Zhou, and H. Wang, "Agile Supply Chain Management over the Internet of Things," 2011.
[31] C. N. Verdouw, A. J. M. Beulens, H. A. Reijers, and J. G. A. J. Van Der Vorst, "A control model for object virtualization in supply chain management," *Comput. Ind.*, vol. 68, no. April, pp. 116–131, 2015.
[32] Y. Wang, X. Geng, F. A. N. Zhang, and J. Ruan, "An Immune Genetic Algorithm for Multi-Echelon Inventory Cost Control of IOT Based Supply Chains," *IEEE Access*, vol. 6, no. January, pp. 8547–8555, 2018.
[33] R. Accorsi, M. Bortolini, and G. Baruffaldi, "Internet-of-things Paradigm in Food Supply Chains Control and Management Internet-of-Things paradigm in food supply chains control and management," *Procedia Manuf.*, vol. 11, no. September 2018, pp. 889–895, 2017.
[34] D.-J. van der Z. Jack G.A.J. van der Vorst, Seth Tromp, "Simulation modelling for food supply chain redesign; Integrated decision making on product quality, sustainability and logistics," *Int. J. Prod. Res. Simul.*, pp. 1537–1546, 2010.