

The Impact of Digital Technology and Industry 4.0 on Enhancing Supply Chain Resilience

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Abstract

Globalization has been increased and generates more complex supply networks and connections. Therefore, supply chains are facing unforeseen disruptions that can halt production and cause delays in providing service. McKinsey reported that only 21% of supply chain organizations believe they have a high resilience network during the COVID-19 pandemic. Most organizations face different challenges to keep their network active during COVID-19 due to a lack of transparency through the network. COVID 19 pandemic expedite the activities of transferring to digitalization among leaders. In this study, the impact of implementing blockchain and Industry 4.0 have been discussed. A supply chain management company are considered to evaluate the impacts of digitalization. A discrete event simulation has been run with two scenarios (scenario one: no digitalization, scenario two increase the transparency by implement digitalization). The results confirm on average, a 17% improvement in resilience level by increasing transparency.

Keywords

Supply Chain, Resilience, Industry 4.0, Blockchain, Transparency

1. Introduction

All supply chain stages, including manufacturers, distributors, and retailers, are getting more disruption due to their complexity and globalization. These complexities escalate tasks such as accurate demand forecasting and allocating requirement time, resources, and labor to avoid the shortage and reduce the related costs. Significantly, now these days, disruption events and their consequences on supply chain networks are growing fast due to more international connections worldwide. For instance, the COVID-19 pandemic is one of the rare disruptions with high severity that poses fundamental challenges to the supply chain network. This challenge is forcing companies to redesign their supply networks to be more resilient. After COVID 19 pandemic with its vast impacts on the supply chain, companies and organizations have highlighted digitalization and employing blockchain as the best approaches to speed up their recovery processes and back to operational statuses.

In supply chain management models, supply chain resilience management has been growing among the research community. Since supply chain resilience management was suffering from disruption risk and influenced by digital technology, it will be practical to generate a relationship between digital technology (such as industry 4.0 (Moore, 2019) and blockchain (Briefing, 2015) and supply chain resilience management (Taghizadeh, E., Abedzadeh, M., & Setak, M., 2017; Tahami, H., Mirzazadeh, A., & Gholami-Qadikolaei, A., 2019). For instance, UPS and SAP collaborated and provided a platform that allows UPS to manufacture items using 3D printing directly at distribution centers (UPS, 2018). This new technology generates a faster, more efficient, and more resilient network

for UPS. Besides, DHL employs the resilience360, a useful framework for managing disruption risk by enhancing transparency, mapping the supply chain end-to-end risk profiles, and identifying vulnerable hotspots to mitigate disruption consequences (DHL, 2018). RiskMethod GmbH introduced a platform combining blockchain technologies with supply chain resilience approaches, including different modules such as 'Risk radar,' 'Impact analyzer' and 'Action planner' for risk monitoring and mitigation action in real-time to keep the supply chain resilience at an acceptable level (Riskmethods, 2018). Juniper Research (Windsor Holden, 2017) verified that around 40% of company founders, CEOs, managers, and information technology (IT) specialists announced either considered deploying or were in the process of deploying blockchain and industry 4.0 technology for their companies to mitigate risk disruption. The recent Eyefrontsport (Eyefortransport, 2017) report revealed that around 60% of supply chain executives confirmed to have engaged with digitalization, which increases their business value and grow their resiliency.

In academic and industry lectures and research studies, the interrelations between digital technologies and supply chain resilience management are at the beginning stage and need more conceptual and experimental studies (Dmitry Ivanov, 2019). In this study, we implement a case study to discuss and provide a framework for integrating digitalization concepts such as blockchain and industry 4.0 with supply network operational tasks that can influence performance indexes and the network's resilience level. Disruption events such as fires at disruption centers, natural disasters like floods or earthquakes, or labor strikes at transportation companies can affect the entire supply chain and are required to identify in proper time to run an appropriate mitigation strategy. Digitalization is the high-rank solution to overcome this obstacle (Ho, 2015; Simchi-Levi, 2015). Therefore, understanding the contribution and the interplay of digital technologies on supply chain resilience management requires more attention and further studies. This study verifies the role of digitalization by demonstrating the results of the impact of employing blockchains and industry 4.0 on supply chain resilience management through a real case study.

To the best of our knowledge, this is the first study that quantifies the supply chain resilience by combing the digitalization technologies with operational indexes to mitigate the supply chain risk disruptions. This paper highlights the requirements of looking at digitalization to boost resilience management in the complex supply network. This study explores how blockchain and industry 4.0 affect mitigating risk disruption and enhance supply chain resilience management. The following questions are answered :

- What relationships exist between digitalization technology (blockchain and industry 4.0) and supply chain resilience management?
- How can digitalization boost the supply chain resilience management and analysis?
- How can digitalization improve supply operational indexes such as total cost and service level?

The paper's remainder is organized as follows: Section 2 provides a review of critical relevant literature. Section 3 presents the proposed methodology of the combination of digitization and resilience management. Section 4 discusses details on running the discrete-event simulation with proper scenarios to check our approach. A real network case study and the computational results have been described in section 5. Finally, Section 6 concludes and provides directions for future research.

2. Literature Review

2.1 Digital Technology

Digital technology has gained the attention of leaders and managers in various industries over the last few years. It makes it easy to transform data that have been stored in unstructured excel sheets, local databases, and ERPs systems. The critical decision, strategy planning, demand forecasting, and resilience management have relied on accurate and organized data; digital technology can centralize all data sources to extract and share accurate and real-time data with all stakeholders to make appropriate decisions in uncertain situations. Digital technology can provide the tools to collect information straightforward by utilizing simple RFID, blockchain, and IoT technologies. Decision-making tools and approaches have been leveraged, especially in an uncertain environment, via adopting digital technology. One area where digital technology could improve is the supply chain resilience management by suggesting the proper mitigation strategies in real-time. Digital technology can provide a platform for identifying and evaluating risk by enhancing visibility through the whole supply network. The data collection and sharing with all network roles, digital technology can provide an attitude to move from unknown situation to known action by allocation resources or signing back up the contract, and it is a powerful approach to increase the resilience level. Besides these advantages of digital technology, a few research studies are looking at the relationship between digital technology and resilience management (Sneeringer, 2021).

5.2 Industry 4.0

Industry 4.0 is recognized as new smart and autonomous in manufacturing and production sections. Its overall aim is to integrate information technologies, data analysis, and communication with operation systems during manufacturing and production to minimize cost, increase productivity, and improve quality (Wang, Y, Ma, H.S., Yang, J.H., Wang, K.S, 2017; Sabina Jeschke, Christian Brecher, Tobias Meisen, Denis Özdemir, Tim Eschert, 2016). Besides this advantage, there are a few disadvantages: lack of perception to implement industry 4.0 and estimate related costs; the most popular one is following the new adoptions and evaluations by all team members in companies (Yongxin Liao, Fernando Deschamps, Eduardo de Freitas Rocha Loures & Luiz Felipe Pierin Ramos, 2017; Sara Saberi, Mahtab Kouhizadeh, Joseph Sarkis & Lejia Shen, 2019). Research studies are categorized Industry 4.0 into two groups: 1. manufacturing technologies such as additive manufacturing, drones, and sensors (Gibson, I., Rosen, D. W., & Stucker, B. , 2014), 2. Digital information technologies such as cloud computing, simulation, blockchain, and big data. A recent study analyzed the application of industry 4.0 in terms of sustainability implications (Chunguang Bai, Patrick Dallasega, Guido Orzes, Joseph Sarkis, 2020). A hybrid multi-dimensional framework, including various economic, environmental, and social attributes, is introduced to evaluate industry 4.0 technology performance on the company's sustainability. However, there is a considerable lack of investigating the relationship between resilience and industry 4.0 in various industries. Recently, Industry 4.0 demonstrates a high impact on improving supply chain resilience, especially during the COVID19 pandemic. Industry 4.0 seeks to overcome supply challenges such as global disruption, demand uncertainty, long lead times, high labor and material costs, and low productivity to improve resilience (Sunil Luthra, Sachin Kumar, 2018).

5.3 Blockchain

In research and various studies focus on demand and inventory data to collect, validate, analyze, and share with other players in the supply chain because customers' demand needs to forecaster accurately for efficient production planning and inventory control procedure to avoid any lost demand (Christos S. Tsanos, Konstantinos G. Zografos, 2016; Nguyen Quoc Viet, Behzad Behdani, Jacqueline Bloemhof, 2018). One of the critical technologies that can help leaders in the supply chain plan more efficiently by relying on accurate data is blockchain. Blockchain can directly create a connection between all players and individual systems in the supply network. Each player can have their private systems, and blockchain can keep all systems secure by connecting with creating a connection between keys in each system (Ana Reyn, Cristian Martín, Jaime Chen, Enrique Soler, Manuel Díaz, 2018). Overall, blockchain enhances transparency and visibility through the network by providing a secure connection between various databases and systems running at each actor's side, which can count as a considerable advantage of applying blockchain. In this uncertain environment, supply chain managers, researchers, and leaders found the impact of considering the blockchain to enhance their network's resilience by making practical and efficient decisions with accurate and real time data (Kersten Wolfgang, Blecker Thorsten, Ringle Christian , 2017). Blockchain brings enormous benefits of making paperwork processing easier to identify and evaluate risks in the whole network and create the framework for developing the proper mitigate strategies (Tian, 2016). Resilience management research on the blockchain is still at the beginning steps, and it has many benefits to look into possible applications that may enhance resilience and reduce the cost to convince the manager to adopt this technology for the store, sharing, and analyzing the real time data. The proof of concept needs to demonstrate how blockchain technology can impact operational planning, demand forecasting, and inventory planning to avoid halt production. It is clear; there is still a lot of research opportunity to investigate the relation between supply chain resilience management and blockchain technology, which is the main contribution of this study.

3. Method

In this study, to assess the advantage and impact of implementing digital technology on resilience supply chain management, a simulation model has been provided to analyze three “what-if” scenarios. A supply chain network including warehouses, carriers, suppliers, and retailers (Figure 1) has been considered, and the flow of good and related information between each player has been simulated. In this section, the logistic network is first described, and then a discrete event-based simulation is developed from the Simpy Python (Simpy, 2002) package scratch. It demonstrates how data and information sharing by applying industry 4.0 and blockchain can improve demand forecasting, inventory, and resource management to enhance resilience during the running simulation.



Figure 1. Supply chain network

5.1 Supply chain Network design

A supply chain network with different nodes, including suppliers, warehouses, and retailers, has been considered. In this case study, three suppliers (S1, S2, and S3), two warehouses (W1 and W2), and five retailers (R1, R2, R3, R4, and R5) are considered, which provide two final products (P1 and P2) based on retailers' demands. Two products can be sold in each retailer location, and their demand (D1 and D2) follows the normal distribution with different mean and standard deviation ($N_1(\mu_1 = 100, \sigma_1^2 = 16)$ and $N_1(\mu_2 = 55, \sigma_2^2 = 64)$) based on retailer location and historical data. Once retailers have customers' demand, retailers check the inventory level and place an order to their supplier requesting the shipment products. When suppliers receive the retailers order, it starts to ship products by considering their shipment policy (such as shipment frequency and capacity) to warehouses. Each retailer has access to specific warehouses with limited capacity. In this study, the lead time between each component (suppliers and warehouse, warehouses, and retailers) and other information are summarized at Table 1. Whenever suppliers and warehouses try to satisfy the retailers' demand, sometimes demand can be lost due to unexpected disruptions in suppliers' location or warehouses. In this study, a disruption scenario has been generated to simulate the real-world case study and analyze how digital technology can help supply networks avoid lost demand and its high cost. In the following section, simulation model and its expected output for our specific case study have been discussed in the details.

Table 1. Shipment data for supply network case study

Source	Target	Leadtime (Days)	Shipment Frequency	Shipment Capacity (Unit)
S1	W1	2	Every 2 days	1000
S2	W1	3	Every 5 days	1000
S3	W1	4	Every 2 days	1000
S1	W2	2	Every 3 days	2500
S2	W2	2	Every 4 days	2500
S3	W2	3	Every 6 days	2500
W1	R1	5	Every 2 days	1400
W1	R2	2	Every 2 days	1400
W1	R3	3	Every 1 days	1400
W1	R4	6	Every 1 days	1400
W1	R5	1	Every 1 days	1400
W2	R1	3	Every 3 days	2100
W2	R2	4	Every 3 days	2100
W2	R3	3	Every 2 days	2100
W2	R4	2	Every 1 days	2100
W2	R5	5	Every 2 days	2100

5.2 Simulation mode and data

After the supply, the network has been mapped, and its information details have been deployed, a discrete-event simulation has been developed to analyze the supply chain performance indexes when disruption happens through two scenarios (details in sections 5.1). A specific python package has been implemented to analyze the organizational process, such as demand forecasting, inventory management, and transportation management. A module has been designed to represent the inventory flows and placing orders. All events are generated using event generating, and all information such as demand and inventory level located each warehouse and suppliers, and inventory in transition, and lost demand are stored in the database tables. Following this methodology, we have obtained the performance metrics such as delay delivery, lost demand, transportation, inventory, and total cost at each retail store. Our overview of approaches steps presents in Figure 2.

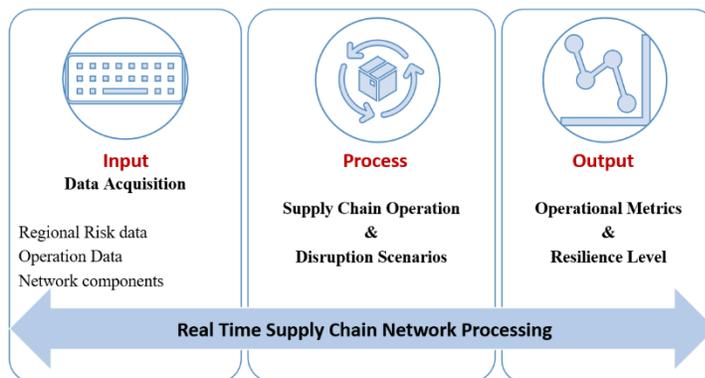


Figure 2. Supply chain network simulation steps

Our methodology starts with data acquisition from local database, secondary data sources such as obtaining the regional risk from IHSMARKIT (ihsmarkit, 2021) , and network components. In the second step after supply network configuration, each node in different roles (suppliers, warehouses, and retailers) will be shut down for a short time, follows by uniform $U(4,10)$ weeks during the simulation running time. During the simulation, the supply chain operating as regular, and the inventory follows will be captured. Finally, the last step, resilience level (demand filled rate Eq. 1), and operational metrics (such as cost and delay delivery) are measured and evaluated. All the results reported in section 5 are obtained using python packages.

$$RL = \frac{\sum_{t=0}^T \left(\frac{\text{Satisfied Demand in time } t}{\text{Total Demand in time } t} \right)}{T} \quad (1)$$

In Eq. 1, T is the total simulation time (planning horizon), and this equation can be used for each node, but in this study, our focus is on the retailers and their customer demands. We can have five resilience levels for five retailers, and a simple weighted summation can obtain total resilience with equal weight for each retailer.

5. Results and Discussion

5.1 Scenario Generation

Given that supply chain disruption events have been increased and its impacts can be mitigated by implementing digitalization such as blockchain and industry 4.0. In this study, we carefully investigate the impact of digitalization on actual network resilience. For this purpose, we designed three scenarios:

- **Typical Scenario (SC0):** without implementing the digitalization and store information or data.
- **Digitalization Scenario (SC1):** implementing blockchain and industry 4.0 through our network.

The option of sharing information and data in the whole network has been added to our simulation model. For the first scenario, we will design the typical network, and simulated inventory follows without sharing information between each component. Each node will assume working with reliable components and does not know any disruption that happened in other nodes. However, In the second scenario, implementing the industry 4.0 and blockchain option has been added during simulation, and each component can share their data and information with others, so all nodes know if any disruption happened. They can adjust their operation plans, such as inventory level and ordering process. Industry 4.0 and blockchain are an option to increase transparency.

We evaluated the case study under two scenarios to see the impact of digitalization on supply network resilience. Each simulation scenario is replication ten times, and all results are discussed in the following section. A personal computer with Intel Corei5-6300U CPU (2.4 GHz) with 8.00 GB RAM has been used for our case study.

5.2 Results

In the first step, we compare each retailer's resilience in two scenarios (typical Scenario [SC0] and digitalization scenario SC1). Figure 3 demonstrates a high resilience level with minimum lost demand for SC1 (on average, there 16% changes); it means the company can enhance their transparency and access to update information data by implementing digitalization such as blockchain and industry 4.0. Digitalization gives this chance to supply chain managers to evaluate the current network status and, by knowing if any disruption events happen, adjust their operational decision to reduce lost demand.

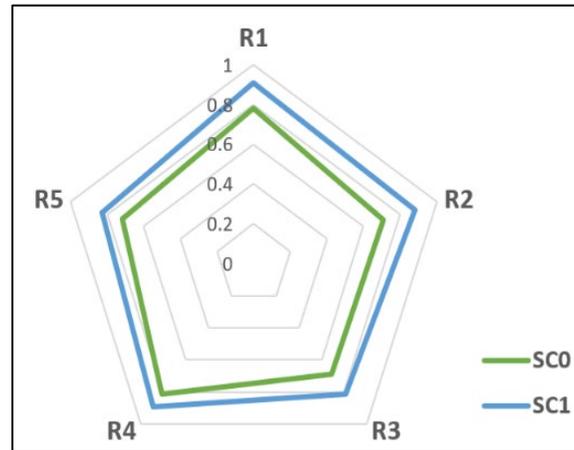


Figure 3. Estimated retailers' resilience under two scenarios [Typical Scenario (SC0), Digitalization Scenario (SC1)]

Other performance metrics need to be evaluated: costs and delay delivery; In this study, we compare inventory and backordered costs at retailers' locations during our simulation under two scenarios when disruption events impact the network. Figure 4 demonstrates how employing digitalization can be affordable, and supply chain managers can increase profit margin by reducing lost demand and accessing the information and data stored by blockchain and industry 4.0. Digitalization provides the opportunity for the company to define the proper risk mitigation strategies at minimum cost.

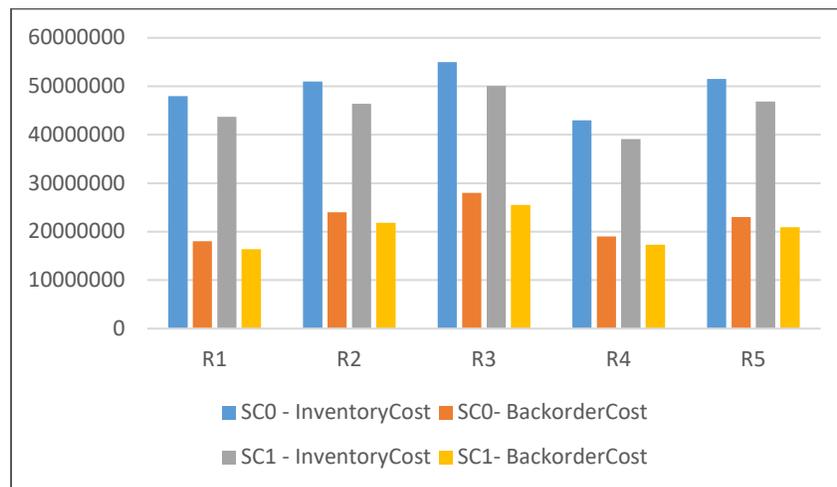


Figure 4. Inventory and backordered costs [Typical Scenario (SC0), Digitalization Scenario (SC1)]

Figure 5 reports the order delivery lead-time delays experienced under two scenarios for each supplier. The total expected delivery lead time from suppliers to retailers is the maximum summation of lead time from suppliers to warehouses and lead time from warehouses to specific retailers. For example, the lead time between S1 and R1 is seven and calculate as follows:

$$\begin{aligned}
 &S1 \longrightarrow W1 \longrightarrow R1 : 2 + 5 = 7 \\
 &S1 \longrightarrow W2 \longrightarrow R1 : 2 + 3 = 5 \\
 &\text{Max}(7, 5) = 7
 \end{aligned}$$

Figure 5 presents how digitalization techniques can help companies to receive their orders at the expected time. We can see in scenario SC1 the average delay is around three days, which is acceptable, but for scenario SC0, this average is around six days, which can make lost demands and a lot of unexpected costs.

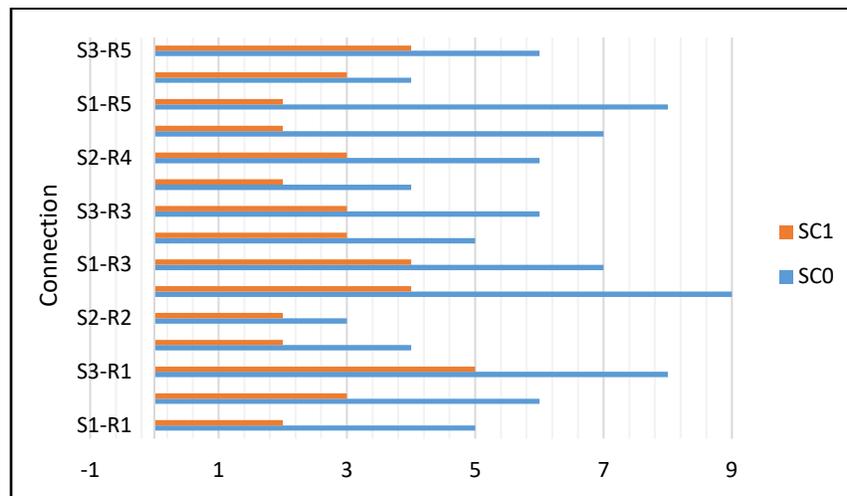


Figure 5. Order delivery lead-time delays [Typical Scenario (SC0), Digitalization Scenario (SC1)]

Overall, the results highlight the importance of digitalization and adequately accounting for sharing accurate data and information in assessing supply network resilience and operational metrics.

6. Conclusion

Accessing and sharing the precise data and information through supply network components is a vital factor of an organization's performance, but there is an obstacle that all network players can trust each other and the accuracy of information. Digitalization could be an acceptable solution that enables them to share accurate information securely and generate more reliable and trustworthy systems in the network. Blockchain and industry 4.0 technology can establish and generate secure and immutable records of data that can be used and view by all network players without allowing them to alert it. This research study demonstrates how employing blockchain and industry 4.0 can impact network resilience and performance indexes. A supply chain simulation model has been developed to certify the benefit of employing these technologies by carrying out two scenarios: one without considering any sharing information and the other sharing information by applying industry 4.0 and blockchain technologies. The results demonstrate that digitalization can enhance supply network resilience when operational disruption events happened at each network players and is a convenient tool to collaborate with trustworthy and in a secure environment. The results confirm a positive impact on reducing lost demand, shortage inventory, and delay delivery with acceptable total cost. Digitalization in supply chain management is still in infancy steps; it can be future research to looking into other applications and benefits in strategic or operational stages that may attract supply chain managers to adopt and implement these technologies.

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