businesses

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Review

Digital-Era Resilience: Navigating Logistics and Supply Chain Operations after COVID-19

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Abstract: The COVID-19 pandemic has highlighted the need for a paradigm shift in supply chain and logistics operations to respond to myriad disruptions. However, this paradigm shift has changed the supply chain to be more resilient, agile, flexible, and adaptable to upcoming disruptions. Hence, a comprehensive guide to understanding, implementing, and harnessing the power of digitization in the face of disruption, leading to a more resilient and adaptive global community, is greatly appreciated. Thus, this study aims to identify the strategies used in the complex and dynamic nature of the contemporary supply chain landscape for these disruptions. Among several strategies adopted and proposed, this systematic review examines overall efficiency and operational resilience, particularly supplier diversification, investment in digital supply chain technology, and adopting flexible manufacturing models. Following a rigorous four-step identification, screening, qualification, and inclusion process, this review focuses on real-time visibility, robust risk management, and data-driven decision making to determine whether future disruptions under digitization are conducive. Therefore, this systematic review, along with these enhanced resilience strategies, will provide a comprehensive resource for practitioners, policymakers, and researchers seeking to navigate and improve logistics and supply chain operations in the face of future disruptions.

Keywords: resilience; COVID-19; supply chain; digitization; transformation

Citation: Kashem, M.A.; Shamsuddoha, M.; Nasir, T. Digital-Era Resilience: Navigating Logistics and Supply Chain Operations after COVID-19. *Businesses* **2024**, *4*, 1–17. https://doi.org/10.3390/businesses4010001

Academic Editor: Lincoln C. Wood

Received: 29 November 2023
Revised: 16 January 2024
Accepted: 19 January 2024
Published: 24 January 2024

1. Introduction

The global supply chain landscape has transformed due to the COVID-19 pandemic. To adjust to the new normal, recent research has also been actively examining several aspects of supply chain management, such as reverse logistics to design and plan shorter supply chains for significant objects, as for resilience in logistics and supply chain operations [1,2]. Furthermore, many experts have investigated the many aspects and sub-aspects of the supply chain's resilience, emphasizing the significance of organizational capability, cooperation, adaptability, and humanitarian values [3]. Thus, integrating supply chain management techniques to improve operational performance is becoming more and more important due to this pandemic. Hence, post-pandemic research has highlighted the need for supply chain resilience to build more robust and adaptive supply networks that can withstand disruptions [4,5] and explored ways to improve resilience, including dual sourcing, demand forecasting models, and technology adoption [6].

Globally, supply chains have been disrupted by the COVID-19 pandemic, for example, industrial facility closures, restricted travel and labor shortages, and widespread delays and shortages in several businesses [7]. These disruptions have made clear how important it is to have flexible, agile supply networks to adjust to unexpected difficulties [8]. Hence, with digitization, new metrics and models are being developed to assess the resilience of supply networks to unexpected shocks, protect product availability, and reduce production downtime [9]. In this case, research explores how artificial intelligence, blockchain, and Internet of Things (IoT) applications can improve real-time visibility, risk management, and decision making during disruptions [10]. Similarly, according to research, businesses use data analytics and digital technologies more frequently to strengthen their supply chains. However, these tools allow for real-time monitoring, demand forecasting, and inventory optimization [11]. Additionally, these technologies enable companies to make more informed decisions, respond faster to disruptions, and improve overall supply chain efficiency [12]. Hence, this digital transformation trend will probably continue to shape the logistics landscape in the post-pandemic world.

Furthermore, the pandemic accelerated the localization of supply chains near-shore [13]. For example, business organizations are rethinking their reliance on outside suppliers and exploring local alternatives [14] to shorten lead times and strengthen supply chains [15]. However, academics have looked at the operational and economic implications of the trend, including potential costs [16]. For example, supply chain participants are working together to improve reverse logistics methods in the wake of COVID-19 and to increase efficiency and sustainability through alliances between retailers, manufacturers, and logistics companies [17,18]. In a sense, this collaborative strategy increases trust and helps to manage risk by minimizing the impact of any disruption through improved communication and collaboration across the supply chain using digitization [19]. Thus, a comprehensive understanding of the impacts of pandemics on logistics and supply chain operations with a focus on enhancing resilience can be an important input for a systematic review.

2. COVID-19 and Disruptions

The supply chain landscape faces multifaceted challenges, including production disruptions, industry-specific impacts, and global trade complexity [20]. Sudden demand changes and inventory dilemmas further complicate matters, while supplier relationships are tested with dependencies and bankruptcies [21]. The crisis prompted accelerated technology adoption and revealed the important role of government intervention [22]. Communication disconnects and workforce challenges add layers of difficulty, in addition to transportation issues and financial implications [23]. Among these challenges, the spotlight on sustainability and resilience prompts strategic reflection, emphasizes the importance of risk management, and gathers valuable lessons for future preparedness. Henceforth, this philosophy is based on the supply chain issue that has been recently documented in the literature [24–27] and tabulated as follows (Table 1):

Table 1. Different types of crises and disruptions characteristics.

Types of Crises and Disruptions	Characteristics
Poverty	✓ Malnutrition in economically undeveloped countries
Unemployment	✓ Job loss leading to financial difficulties
Economic crisis	✓ Sharp transition into recession ✓ Class conflict and societal changes ✓ Market crashes, strikes, labor shortages
Financial crisis	✓ Banking crisis, speculative bubbles, crashes ✓ International financial crisis
Environmental crisis	✓ Environmental disaster due to human activity ✓ Natural disasters like volcanic eruptions, landslides, etc. ✓ Loss depends on population resilience
International crisis	✓ Far-reaching consequences affecting the world
Informational	✓ Lack of important information or organizational records ✓ Public or confidential information is missing

Table 1. *Cont.*

Types of Crises and Disruptions	Characteristics
Physical	✓ Equipment problems, loss of supplier, key plant disruption
Human resources	✓ Loss of key executive member ✓ Workplace violence, vandalism
Reputation	✓ Rumors or gossip negatively affecting organizational reputation

Therefore, the COVID-19 pandemic triggered a profound impact on supply chains, exacerbating poverty in underdeveloped countries and fostering challenges like malnutrition [28]. Limited resources and opportunities in these regions contribute to widespread malnutrition, hindering individual and social progress [29]. The pandemic-induced economic downturn led to increased unemployment, creating financial hardships that extend beyond individuals to affect families and communities [30]. Navigating these challenges requires building resilience and fostering inclusion to mitigate the long-term consequences on communities [31]. The resulting economic crisis, marked by recessions and social upheavals, intensifies class conflicts and underscores the need for comprehensive strategies to address the multifaceted impact on society.

3. COVID-19 and Supply Chain Resilience

3.1. Vulnerabilities, Flexibility, and Resilience in the Pandemic

The post-COVID-19 environment has significantly changed how organizations respond to unexpected shocks. In this case, the pandemic provided a profound reminder of the value of flexibility and resilience [32]. Nowadays, businesses place a lot of weight on risk mitigation and backup planning, which ranges from labor shortages to supply chain disruptions [33]. For instance, they use flexible production models, invest in digital supply chain technologies, and diversify their suppliers [6]. Thus, these digital strategies improve their ability to deal with uncertainty on a daily basis, guaranteeing a stronger response to future crises [8].

Organizations are increasingly prioritizing the ability to manage unexpected events in an era characterized by increased complexity and unpredictability in the business landscape [34]. However, developing flexibility involves diversifying supplier networks, implementing multi-modal transportation options, and increasing close collaboration with suppliers to enhance responsiveness to unexpected changes [35]. Usually, businesses implement sophisticated strategies to protect operations from unexpected disasters, such as natural disasters, supply chain disruptions, and international conflicts [8]. By carefully examining past data, creating scenarios, and applying cutting-edge technology, for instance, companies hope to create robust backup plans to keep things running if something goes wrong. Thus, this study looks at the dynamic capability of rapid response and recovery from unexpected shocks in addition to a proactive detection of vulnerabilities.

3.2. Fluctuating Demand and Disruptions in the Pandemic

After COVID-19, product availability has also changed. The pandemic highlighted the importance of local sourcing and revealed the vulnerability of global supply systems [36]. Firms prefer more decentralized strategies after reassessing their reliance on single-source suppliers [37]. Literally, effective inventory control and data-driven forecasting are now essential to adjust to changing demand trends and reduce the possibility of overstocking or stock-out [38]. This is especially important for areas where customer demand changes or disruptions can lead to massive product shortages [7]. Experts suggest investigating improved inventory management techniques, demand forecasting, and predictive analytics to ensure that items are regularly available to customers [39]. As a result, the primary goal of recent research should be to guarantee product availability. According to Chauhan et al. [40], this may be recommended for future firm sustainability and profitability expansion. However, with the implementation of automation and technology, businesses now maintain improved inventory management, shorter lead times, and guaranteed product availability [41] to reduce excess inventory, shorten lead times, and increase order fulfillment efficiency [9].

3.3. Production Downtime, Automation, and Digitization in Supply Chains

Reducing production downtime is the subject of the most current research in order to maintain operational effectiveness and competitiveness [8]. Predictive maintenance strategies, condition monitoring, and real-time data analysis are the key areas of study in this field, since automation and just-in-time manufacturing procedures are becoming more and more dependent on them [38]. Moreover, real-time monitoring and self-diagnosis in industrial settings are made possible by the advent of Industry 4.0 technologies, such as artificial intelligence (AI) and the Internet of Things (IoT) [42]. However, Sudan et al. [9] emphasized that, even after considering the benefits of digitization, the ultimate objective is to move away from reactive maintenance practices and toward proactive, data-driven strategies that will reduce manufacturing downtime costs and increase overall productivity.

On the other hand, reducing manufacturing delays has become a top priority for companies operating in the aftermath of the epidemic [8]. Predictive maintenance and remote monitoring solutions have become more critical to businesses as they realize that extended disruptions can have adverse financial effects [43]. For instance, to reduce unexpected downtime, equipment faults are detected and prevented using machine learning algorithms and IoT technologies [44]. Likewise, to lessen the effect of unforeseen occurrences like labor shortages or lockdowns, many organizations were also rethinking and shifting their workforce management practices by providing remote work choices and flexible scheduling [45]. By implementing flexible production models, investing in digital supply chain technology, and diversifying their suppliers, they could increase operational resilience and overall efficiency (Table 2).

Table 2. (a–c): Post-COVID-19 shifts: diversifying suppliers, digital tech, and flexible production in supply chains.

	(a): Adopting Flexible Production Models [46–51]
Facts	- Flexible production models are essential for adapting to changing demand patterns and scalability in manufacturing to adjust production volumes and product lines quickly.
Real Instances	- An automaker adopts a “just-in-time” production approach to meet shifts in demand for electric vehicles versus traditional gasoline-powered cars.
Post-COVID-19 Consequences	- Enhanced adaptability to changing market conditions and demand patterns; - Reduced excess inventory and associated costs; - Data-driven decision making; - Quick response to disruptions in production; - Efficient resource allocation; - On-demand and customized production; - Better scalability and cost optimization.
	(b): Investing in Digital Supply Chain Technologies [52–55]
Facts	Digital technologies like the IoT, AI, blockchain, and data analytics have become essential to monitor and optimize supply chain operations for improved visibility, efficiency, and resilience in supply chains.
Real Instances	- An e-commerce company implements an AI-powered demand forecasting system to optimize inventory levels and respond to fluctuations in customer demand.

Table 2. *Cont.*

Post-COVID-19 Consequences	- Better visibility and real-time tracking of inventory; - Improved demand forecasting and streamlined inventory management; - Faster response to supply chain disruptions; - Encouraging competition and innovation among suppliers; - Efficient order tracking and processing; - Automation of routine tasks.
(c): Diversifying Suppliers [54,56–61]	
Facts	- Companies have realized the importance of reducing dependency on single suppliers and diversifying their supplier base to mitigate risks associated with supply chain disruptions.
Real Instances	- A smartphone manufacturer diversifies its suppliers by sourcing components from multiple countries to reduce the risk of supply chain disruptions.
Post-COVID-19 Consequences	- Reduced vulnerability to supply chain disruptions; - Enhanced negotiation power with suppliers; - Enhanced supplier risk management; - Reduced dependency on a single source; - Increased resilience in the face of supply disruptions; - Broader geographic reach for sourcing.

So, data analysis, technology innovation, and strategic planning are being used by organizations to improve their operations and maintain their competitiveness in a global economy that is undergoing continual change. Therefore, the pandemic's important lessons have spurred a move towards proactive risk management, diversified supply chains, and technology-driven solutions for continuity and resilience.

3.4. COVID-19 Disruptions and Digital Technologies

The IoT, blockchain, and AI address supply chain problems by adopting flexible production processes, investing in digital supply chain technology, and diversifying suppliers, which are summarized in Table 3:

Table 3. (a): Supply chain challenges and digital technologies in diversifying suppliers [54,62–64]. (b): Supply chain challenges and digital technologies in investing in digital supply chain technologies [52,62,65,66]. (c): Supply chain challenges and digital technologies in adopting flexible production models [42,62,66,67].

(a)	
IoT	- Real-time tracking of supplier performance; - Demand forecasting based on market data and supplier collaboration; - Integration with supplier systems; - RFID and sensors for inventory management.
Blockchain	- Supplier transparency; - Secure supplier identity; - Immutable records of transactions; - Smart contracts for automated payments; - Enhanced trust and integrity in the supply chain.
AI	- Predictive analytics for supplier selection; - Supplier risk assessment; - Market analysis for identifying new suppliers.

Table 3. *Cont.*

(b)	
IoT	- Enhanced visibility into supply chain operations; - Improved demand forecasting through AI; - Real-time monitoring and alerting for supply chain disruptions; - Streamlined communication with suppliers and customers; - Inventory optimization through AI algorithms.
Blockchain	- Improved traceability of goods along the supply chain; - Reduction in fraud and counterfeiting; - Enhanced supply chain visibility and transparency; - Efficient and automated payments; - Reduced paperwork and manual processes.
AI	- Automated procurement and order management; - Real-time demand sensing; - Inventory optimization; - Data-driven decision making for investment and capacity planning; - Just-in-time production; - Adaptive manufacturing; - Dynamic routing of goods and resources.
(c)	
IoT	- Real-time data on machine performance and production processes; - Collaborative robots and automation for rapid reconfiguration; - IoT-enabled predictive maintenance for machinery and equipment; - Real-time production data analytics for efficient resource allocation.
Blockchain	- Smart contracts for automated production processes; - Enhanced collaboration between supply chain partners; - Improved quality control through blockchain-based tracking of product data; - Reduced lead times and lead time prediction; - Secure and transparent data sharing.
AI	- Real-time monitoring of production lines and equipment; - Demand-driven production adjustments based on market insights; - Dynamic scheduling and resource allocation; - Quick response to changes in demand or supply.

Therefore, Table 3 clearly summarizes how blockchain, IoT, and AI technologies might address particular supply chain issues digitally.

In terms of supply chain resilience, the following is a better manner anticipated by Alicke et al. [68] based on the overall scenario and the most current report of COVID-19:

- Healthcare emerges at the forefront with 60% regional supply chain coverage, demonstrating adaptability in the face of challenges;
- The automotive, aerospace, and defense sectors, despite prioritizing resilience, lag significantly at 22%;
- Chemical and commodity industries exhibit minimal change in their supply chains with variations arising from sector-specific challenges, such as resource intensity and supplier issues;
- The COVID-19 pandemic has made supply chain risk management a top priority for companies, with 95% adopting formal processes;
- Although 59% implemented new risk management practices, effectiveness varied based on pre-existing risk management maturity;
- Supplier risk monitoring has emerged as a primary focus, although blind spots remain, particularly beyond tier-one suppliers. In terms of supply chain planning, 58% reported better performance, linked to the use of advanced analytics tools.

Despite the hurdles, the pandemic has accelerated digitization in supply chain processes, prompting increased investment in digital technologies.

4. Methodology

The COVID-19 pandemic disrupted transportation and supply chain operations worldwide, emphasizing the need for resilience in these sectors. Conducting a comprehensive analysis of the impact of the pandemic on supply chain and logistics operations for resilience requires a systematic approach to ensure a comprehensive and unbiased evaluation of previous research. Thus, the research question for this review is, "What changes to supply chain architecture are required to enhance resilience in the face of future disruptions, and to what degree did the pandemic reveal vulnerabilities in supply chain designs?" based on a systematic review of studies conducted by Abideen et al. [67]. In addition, the methodology procedures to be followed in carrying out this review are described in the following subsections.

4.1. Information Sources

This study consulted various data sources to offer a comprehensive view of how the pandemic influenced supply chain and logistics operations. At the outset, the authors rigorously searched primary academic databases and reviewed gray literature such as trade journals, government websites, and international organization reports.

4.2. Search Terms

To craft exact search phrases for the systematic review, "COVID-19" and "supply chain"; "COVID-19" and "supply chain" and "logistics"; and "COVID-19" and "supply chain" and "disruption" were among the phrases that were used. To maximize search sensitivity and specificity and the retrieval of relevant studies addressing the complex effects of the pandemic on supply chain resilience and logistics, these terms were customized for each unique database or source, providing a thorough basis for the systematic review.

4.3. Inclusion and Exclusion Criteria

4.3.1. Inclusion Criteria

- Studies conducted from January 2019 onwards;
- Research focusing on the impact of the COVID-19 pandemic on logistics and supply chain activities;
- Studies that investigate strategies and practices to enhance resilience during the pandemic.

4.3.2. Exclusion Criteria

- Studies not published in English;
- Studies with insufficient data or inadequate methodology;
- Duplicates or redundant publications.

4.4. Paradigm of Systematic Review

A rigorous four-step identification, screening, eligibility, and inclusion process for researching the effects of pandemics on logistics and supply chain resilience is part of this systematic review strategy [67]. This approach has been utilized to minimize the potential for bias in study selection, guarantee a thorough retrieval of relevant studies, and ensure that only excellent studies that satisfy predefined criteria are included in the final review (Figure 1).

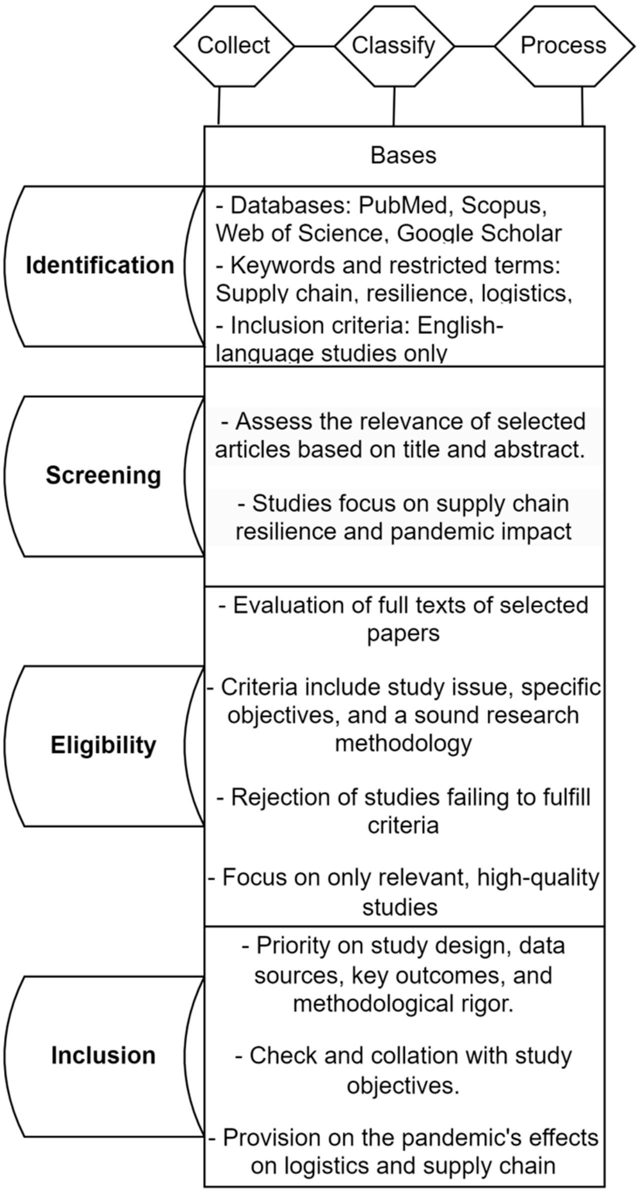

Figure 1. Flowchart of Systematic Literature Review.

4.4.1. Identification

The first step in conducting a comprehensive study on the impacts of pandemics on supply chain and logistics operations for resilience is to find relevant papers. This study used a systematic search and systematic approach involving searching several electronic databases, including PubMed, Scopus, Semantic Scholar, OpenAlex, and Google Scholar, using a mix of keywords and restricted terms related to supply chains, resilience, logistics, and COVID-19. The period covered by this search is from the beginning of the COVID-19 pandemic to the present, and only included English-language studies. This study involved manually searching important publications and conference proceedings on the subject in addition to database searches.

4.4.2. Screening

Screening procedures are essential to guarantee the inclusion of studies that satisfy predetermined criteria after the identification phase. Essentially, this screening process aims to minimize the potential for bias in the studies ultimately selected. Here, the authors individually assessed the relevance of selected articles based on titles and abstracts. The studies that meet the inclusion criteria at this level, with an emphasis on supply chain resilience and the impact of the pandemic on the supply chain, were deemed eligible for review. However, articles that did not fit these requirements were removed.

4.4.3. Eligibility

Once more, based on a thorough review of all the studies, this review analysis used strict criteria. The full texts of the selected papers were evaluated for eligibility based on how well they address the study issue, adhere to the specific objectives of the research review, and have a sound research methodology. Studies that failed to fulfil these requirements were not approved. Thus, this phase ensured that the review contains only relevant, high-quality studies of a diverse nature.

4.4.4. Inclusion

Studies that extracted and synthesized data from these selected studies were included. Sophisticated data extraction methods were used to collect relevant data from each selected study, including the study design, data sources, key outcomes, and methodological rigor. After collecting the data, it was checked whether they met the objectives of the study and the results were collated. Incorporating the most relevant information, this systematic review thoroughly summarizes the impacts of the pandemic on supply chain and logistics resilience. As a result, this rigorous and systematic approach improves the understanding of resilience to global disruptions by providing valuable information on how the pandemic affected logistics and supply chain businesses.

5. Result

The researchers primarily directed their attention towards scholarly articles sourced from the Google Scholar dataset, leveraging its convenience in citation and its wide-ranging audience encompassing various research domains [69].

A swift exploration of both the Google Scholar and PubMed databases unearthed a total of 2519 papers dedicated to the realm of smart transportation. Furthermore, a comprehensive review spanning the period from 2019 to 2023 unveiled the presence of smart transportation- and carbon-related papers in additional repositories such as Scopus, OpenAlex, and Semantic Scholar. The search was refined using specific keywords, namely "COVID19" and "supply chain"; "COVID19" and "supply chain" and "logistics"; and "COVID19" and "supply chain" and "disruption" (as depicted in Table 4). After avoiding repetition, 3169 articles were considered for the citation matrix (Table 5).

Table 4. Systematic literature search and bases of inclusion and exclusion.

Keywords/Search String	Search Engine	No. of Papers	Inclusion and Exclusion Parameters
"COVID19" and "supply chain	Google Scholar	2310	In the Title Year: Any time
"COVID19" and "supply chain" and "logistics"	Google Scholar	86	In the Title Year: Any time
"COVID19" and "supply chain" and "disruption"	Google Scholar	168	In the Title Year: Any time
"COVID19" and "supply chain"	PubMed	209	In the title of the article Year: Any time
"COVID19" and "supply chain" AND "logistics"	Scopus	35	In the title of the article
"COVID19" and "supply chain"	Semantic Scholar	1000	In the title of the article
"COVID19" and "supply chain"	OpenAlex	1000	In the title of the article

Table 5. Number of selected papers published per year from 2019 to 2023.

Year	2019	2020	2021	2022	2023
No. of Papers	3	843	1157	771	395

Following a meticulous analysis, the citation study, presented in Table 6 and covering the period from 2019 to 2023, provided insightful metrics. Notably, the average number of citations per document stood at 47.27, with each paper receiving an average of 3.23 citations. The h-index was calculated at 169, the g-index at 284, and the hA-index at 107, indicating the scholarly impact and influence of the identified articles in the field of smart transportation and carbon-related studies.

Table 6. Citation metrics.

Publication Year	Papers	Citations	Cites/Year	Cites/Paper	Author/ Paper	h-Index	g-Index	hA-Index
2019–2023	3169	149,798	37,449.50	47.27	3.23	169	284	107

6. Discussion

6.1. Major Disruptions in Supply Chain

The supply chain landscape is characterized by various obstacles and challenges that significantly affect various aspects of the global industry. These disruptions include production stoppages, transportation restrictions, labor shortages, and raw material shortages [70]. The automotive industry faces production freezes and reduced demand, while electronics struggles with component shortages and pharmaceuticals face delays (Mallik, 2023). The complex web of global trade is affected by export/import restrictions, port closures, customs delays, and reduced aircraft cargo capacity [71].

Fluctuations in demand add to the complexity, with sudden increases in demand for healthcare contrasting with sharp declines in luxury goods [72]. Inventory challenges arise from stockouts due to panic buying, excess stock of nonessential products, and difficulty in inventory management [49]. Supply chain vulnerabilities are further highlighted by supplier relationship issues, such as reliance on single suppliers, supplier bankruptcies, and the need for contract re-negotiations [73]. However, the integration of technology becomes crucial, resulting in an accelerated need for digital solutions, an increased adoption of the IoT for real-time tracking, and significant growth in e-commerce [74]. Government intervention in the form of regulatory changes affecting logistics and stimulus packages affecting supply chain resilience plays a key role.

Communication disconnects and a lack of real-time information plague supply chain networks, while workforce challenges include remote working difficulties, onsite worker safety concerns, and labor shortages in critical sectors [75]. Transportation problems occur with freight capacity shortages, canceled flights affecting air cargo, and container shortages and delays [76]. On the other hand, effective risk management includes identifying and mitigating supply chain risks, as well as scenario planning for future disruptions [77]. Financial impacts manifest as increased costs due to logistical challenges and revenue loss from production shutdowns [59]. Sustainability becomes a focal point, prompting a reevaluation of global supply chain models with a renewed emphasis on sustainability and resilience [78]. Hence, the following is a summary of these disruptions (Table 7):

Table 7. Major disruptions in supply chain for COVID-19.

Aspect	Description
Disruption Point	✓ Manufacturing Shutdowns ✓ Transport Restrictions ✓ Labor Shortages ✓ Raw Material Scarcity
Industry Impact	✓ Automotive: production halts, demand drop ✓ Electronics: component shortages ✓ Pharmaceuticals: delays
Global Trade	✓ Export/Import restrictions ✓ Port closures ✓ Customs delays ✓ Reduced air cargo capacity
Demand Fluctuations	✓ Sudden demand spikes (e.g., healthcare) ✓ Sharp declines (e.g., luxury goods)
Inventory Challenges	✓ Stock-outs due to panic buying ✓ Overstock in nonessential goods ✓ Difficulty in inventory management
Supplier Relationships	✓ Dependency on single suppliers ✓ Supplier bankruptcies ✓ Contract negotiations
Technology Integration	✓ Accelerated need for digital solutions ✓ Adoption of IoT for real-time tracking ✓ E-commerce growth
Government Interventions	✓ Regulatory changes affecting logistics ✓ Stimulus packages affecting supply chain resilience
Communication Breakdowns	✓ Lack of real-time information ✓ Miscommunication in the supply chain network
Workforce Challenges	✓ Remote work challenges ✓ Safety concerns for onsite workers ✓ Labor shortages in critical sectors
Transportation Issues	✓ Freight capacity shortages ✓ Canceled flights impacting air cargo ✓ Container shortages and delays
Risk Management	✓ Identification and mitigation of supply chain risks ✓ Scenario planning for future disruptions
Financial Impacts	✓ Increased costs due to logistics challenges ✓ Revenue loss from production stoppages
Sustainability	✓ Focus on sustainable and resilient supply chains ✓ Reevaluation of global supply chain models
Lessons Learned	✓ Reflection on crisis response ✓ Strategic changes for future preparedness

Thus, the supply chain landscape undergoes a transformation, emphasizing adaptability, resilience, and sustainable practices to navigate the inherent challenges and obstacles in a global environment.

6.2. Post-Pandemic Resilience and Approaches toward Digitization

The COVID-19 pandemic significantly changed the supply chain management landscape, forcing companies to re-evaluate and restructure their strategies [49]. In this changing environment, the integration of the Internet of Things (IoT) and artificial intelligence (AI) has played an important role in reshaping supply chain operations [63]. Additionally, IoT sensors and devices have improved visibility and tracking capabilities throughout the supply chain [62]. However, these devices can monitor product status and location in real time, allowing predictive maintenance and efficient route planning [41]. Thus, businesses have shortened lead times, improved inventory management, and become more agile in the face of disruptions in conjunction with AI [19].

A prominent application of the IoT and AI in post-COVID-19 supply chain management is predictive analytics [79]. AI algorithms can predict demand more accurately by analyzing historical data, market trends, and external factors [38]. This capability has proven invaluable as companies strive to maintain a lean inventory and reduce the risk of stock-outs or excess inventory [9]. Moreover, IoT sensors have empowered businesses to monitor environmental conditions such as temperature and humidity, ensuring the quality and safety of sensitive products such as medicine and food products [12]. This level of regulation and oversight has become paramount in a world still grappling with the uncertainty of the pandemic.

Another key area where the IoT and AI have made significant inroads is in supply chain risk management. The pandemic exposed vulnerabilities in global supply chains, with disruptions ranging from factory shutdowns to transportation bottlenecks [7]. IoT devices can provide real-time data on potential disruptions, such as equipment failures or traffic congestion, allowing supply chain managers to take pre-emptive measures [9]. AI, on the other hand, can assist in scenario planning, helping organizations to identify and evaluate alternative suppliers or transportation routes in case of emergencies [15]. Post-COVID-19, supply chains have become more resilient and adaptive thanks to the fusion of these technologies [6].

Additionally, the COVID-19 pandemic catalyzed the adoption of the IoT and AI in supply chain management. By harnessing the IoT for real-time tracking and AI for predictive analytics and decision making, enterprises have redefined their supply chain strategies to thrive in an environment marked by ongoing disruptions and uncertainties [49]. Literally, these technologies have enabled organizations to achieve unprecedented levels of visibility, efficiency, and risk mitigation [19]. More specifically, supply chains can attach Internet of Things devices to products or storage containers via GPS satellites to improve shipping and inventory tracking. Still, it has also made them more resilient and capable of addressing the challenges of the post-COVID-19 world [4].

6.3. The Role of Internet of Things (IoT) and Artificial Intelligence (AI) in Supply Chain Strategies for Post-COVID-19 Impact

Global supply systems were affected by the COVID-19 epidemic, underscoring the necessity of robust, flexible, and effective supply chain policies [51]. The combination of artificial intelligence (AI) with the Internet of Things (IoT) has become more important in this setting [79]. The unique functions of the IoT and AI in supply chain strategies are examined in this article (Table 8), along with their distinctions and influence after COVID-19. Usually, the IoT concentrates on gathering and monitoring data in real time, whereas AI employs predictive analytics to improve decision making and optimize every supply chain step. Together, these technologies help to create a more flexible and effective supply chain ecosystem while addressing the issues brought forth by the epidemic.

Supply chains are inherently risky, but with the help of artificial intelligence (AI), organizations can predict risks before they become problems. Early in the shipping process, when mitigation initiatives have the best chance of success, leaders can make data-backed decisions.

Table 8. IoT vs. AI in supply chain strategies.

Aspect	IoT in Supply Chain Strategies	AI in Supply Chain Strategies
Data Collection	Sensors and devices collect data from physical assets, products, and transportation [15].	Analyzes data from various sources, such as historical data, customer trends, and market dynamics [14].
Real-time Visibility	Provides real-time visibility into the location, condition, and performance of assets and products [80].	Predictive analytics and machine learning enable real-time forecasting, demand prediction, and inventory optimization [38].
Inventory Management	Enables RFID and GPS technologies to track inventory, reducing stock-outs and excess inventory [9].	Optimizes inventory levels, identifies demand fluctuations, and minimizes holding costs [66].
Predictive Maintenance	Monitors machinery and equipment conditions, allowing proactive maintenance to prevent breakdowns [41].	Utilizes AI algorithms to predict equipment failures and schedule maintenance based on usage and data analysis [42].
Supplier Collaboration	Facilitates communication between suppliers and manufacturers for efficient order management [19].	Enhances supplier collaboration by automating procurement and optimizing supplier relationships [66].
Route Optimization	Optimizes transportation routes for cost reduction and timely delivery [9].	AI-driven route optimization considers multiple variables like traffic, weather, and fuel costs [52].
Demand Forecasting	Provides fundamental demand insights based on historical data and current trends [4].	Utilizes advanced statistical models and machine learning to predict demand accurately [46].
Risk Management	Offers limited risk assessment capabilities [4].	Assesses supply chain risks in real-time, adapting strategies for changing circumstances [66].
Post-COVID-19 Impact	Strengthens the need for end-to-end visibility, flexibility, and resilience [15].	Accelerates adoption to address the supply chain disruptions and increased demand for e-commerce [66].
Real-World Examples	Amazon's smart shelves use the IoT to track inventory levels, ensuring products are always available for customers. The IoT is widely used in logistics and warehousing [41].	DHL, a global logistics company, employs AI to optimize delivery routes, reducing costs and environmental impact [81,82].

7. Theoretical and Managerial Implications

The COVID-19 pandemic had a wide-ranging and multifaceted impact on supply chain and logistics operations, making a re-evaluation of current thinking and management strategies critical. This pandemic certainly brought attention to the limitations of conventional frameworks for supply chain risk management. Subsequently, supply chain resilience theories underwent changes that included not only risk acceptance and mitigation, but also adaptation through the use of dynamic and adaptive frameworks. Consequently, this theoretical model addresses how manufacturers, suppliers, and customers are interconnected and emphasizes the value of variety, redundancy, and flexibility. Given the significance of supply chain dynamics, insights developed from the multidimensional literature were incorporated into this theoretical framework to help predict and mitigate similar strategies and guidelines for the near future.

The COVID-19 pandemic necessitates a reassessment of current concepts and managerial strategies due to its wide-ranging and diverse impact on supply chain and logistics operations. Undoubtedly, the pandemic has highlighted the shortcomings of traditional supply chain risk management frameworks. And then, the modification of supply chain resilience theories included not only risk acceptance and mitigation, but also adaptability through the use of dynamic and flexible frameworks. Thus, this theoretical model addressed the interconnections between suppliers, manufacturers, and customers, highlighting the importance of flexibility, redundancy, and diversity. With the importance of supply chain dynamism, this theoretical framework incorporated better insights from behavioral economics to better predict and mitigate such behavior in the near future as well.

Supply chain managers wanting to bring production closer to the final consumer must diversify their supplier base to lessen their reliance on a single source through near-shoring or re-shoring. Consequently, real-time monitoring and data analytics investments are essential to watch inventory, demand, and any interruptions and enable faster responses. Once more, supply chains ought to be flexible enough to accommodate sudden distribution, transportation, and manufacturing changes in light of implementing solutions for just-in-case inventories. So, when demand exceeds supply, establishing tenacious supplier ties via cooperation and long-term collaborations may be helpful during disruptive periods and result in preferential treatment.

8. Conclusions

The global COVID-19 pandemic significantly affected supply chain and logistics operations. Supply chain vulnerabilities were made public by this exceptional catastrophe, which prompted a flurry of research to study its aftermath and devise methods for strengthening resilience against future shocks. This study has provided insightful information on how the logistics and supply chain sector is dynamic and changing. These observations are crucial for businesses looking to create robust, adaptable, and agile supply chains that might endure obstacles and disruptions in the future as the logistics and supply chain sector develops. In order to maximize product life cycles and reduce waste, future research should focus on re-manufacturing, refurbishment, and recycling. Future studies should also build innovative circular supply chain models to balance environmental and economic objectives successfully. Ultimately, research needs to be conducted on supply chain resilience, reverse logistics, and the circular economy in the post-pandemic period to ensure a sustainable and resilient future for supply chain operations.

Author Contributions: Conceptualization, methodology, literature review, resources, M.A.K., T.N. and M.S.; writing—original draft preparation, writing—review and editing, M.S., M.A.K. and T.N., Software—M.A.K. and M.S., Revisions based on reviewers' comments—M.S. and M.A.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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