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The Implications of Digitalization in Logistics after COVID-19

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Abstract

The COVID-19 pandemic exposed critical vulnerabilities in supply chain management, particularly highlighting the risks associated with just-in-time and single-source supply chain models. These weaknesses became evident when delays in the delivery of essential supplies jeopardized public health. Consequently, the digitalization of supply chains has emerged as a pivotal strategy to enhance real-time visibility of product status, location, and other critical attributes. COVID-19 accelerated digital supply chain planning, with many organizations pivoting towards e-commerce and digital transformation to maintain competitiveness. Technologies such as the Internet of Things (IoT), Big Data, Digital Twin, Artificial Intelligence (AI), Machine Learning (ML), Blockchain, and Industry 4.0 have become instrumental in facilitating this transformation. This study conducted a systematic literature review following PRISMA guidelines, analyzing 23,338 initial articles from the Scopus database and ultimately selecting 23 articles for review after applying rigorous inclusion and exclusion criteria. The analysis focused on primary research articles published between 2020 and 2024, examining the implementation and impact of digital technologies in logistics during and after the COVID-19 pandemic. The findings provide valuable insights for practitioners and researchers, emphasizing key areas for future research in logistics digitalization and technology adaptation in the post-pandemic era.

Keywords: Artificial Intelligence (AI), Big Data, Blockchain, COVID-19, Digital Supply Chain, Digital Transformation, Digital Twin, Industry 4.0, Internet of Things (IoT), Logistics, Machine Learning (ML), Supply Chain Management.

Introduction

The technology solution suppliers, logistics service providers, and end-user companies are the primary players in the digitalization of the logistics supply chain market. Manufacturers of linked devices and other types of hardware, as well as software developers, are examples of technology solution providers. Consultants, technology consulting service providers, integrators, and implementation service providers, among others, are referred to as "technology service providers." Accenture Plc., IBM Corporation, SAP SE, and Capgemini are just a few of the well-known technological solution providers in the industry (1). In 2019, the digitalization of the logistics and supply chain sector was valued at around USD 12 million, with projections indicating it could reach USD 24 million by 2027. The market is expected to grow at a compound annual growth rate (CAGR) of 8.5% between 2020 and 2027. Key technology service providers in this space include companies like The Supply Chain Consulting Group Ltd., REPL Group Worldwide Ltd., and Brain & Company Inc. A major factor driving this growth is the rapid industrialization in developing countries, which has led to a significant rise in the establishment of manufacturing facilities. The production facilities of several multinational corporations are located in various developing nations. The development of international corporations in these nations produces a significant demand for high-speed internet access to expedite a wide range of business processes. Emerging technologies such as the Internet of Things (IoT) and artificial intelligence (AI) are enabling real-time monitoring, tracking, and predictive analytics, thus significantly improving logistics efficiency and safety (2). The COVID-19 pandemic has acted as a catalyst for digital transformation in logistics. Lockdowns and restrictions on movement disrupted supply chain operations globally, forcing industries to adopt digital technologies to ensure business continuity. Technologies such as IoT-enabled systems facilitated real-time tracking and monitoring, mitigating operational disruptions and enhancing transparency for

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service providers and consumers alike (3, 4). However, the pandemic also revealed critical gaps, including the limited scalability of digital solutions in small and medium-sized enterprises (SMEs) and the underutilization of data-driven systems in developing economies. Since December 2019, the COVID-19 virus pandemic has had an impact on every company in every country across the world (5). As COVID-19 cases surge, governments around the world have implemented restrictions on the movement of individuals and goods. This has caused significant disruptions in the industrial sector, with facility shutdowns and decreased production levels leading to substantial losses. These challenges have also negatively impacted the logistics industry, which has struggled with the resulting operational constraints. Furthermore, government-imposed social and physical isolation laws have forced logistics service providers to curtail their activities to maintain a profit margin. Those working in the logistics and supply-chain industries, for their part, are relying on digital technologies to counteract the outbreak's negative impact on conventional logistical approaches (6). The digitalization of the logistics supply chain sector is being aided as a result. Nonetheless, decreased manufacturing rates are restricting the full use of fleets, causing tremors in the operations of logistics service providers and, as a result, a slower rate of development in the logistics supply chain industry as a result of digitalization. Both primary and secondary data sources were utilized to estimate the global market size for digitalization in logistics and supply chain management (7). In the post-COVID-19 era, the focus has shifted to building resilient, flexible supply chain systems through innovation and automation. This includes strategies such as integrating blockchain for secure data sharing, AI for demand forecasting, and IoT for operational visibility. These technologies not only enhance productivity but also address workforce challenges by automating repetitive tasks and reducing reliance on human labor. The present study aims to provide an in-depth analysis of the post-pandemic digitalization landscape in logistics, focusing on the integration of AI, IoT, and robotics to address existing gaps and align with emerging market trends. By doing so, the research highlights actionable insights for logistics professionals and offers specific recommendations for future research to further enhance digital transformation in the sector.

Technology and logistics Sector

Supply networks were abruptly disrupted and taken aback when the transportation of commodities came to a halt as a result of the COVID-19 pandemic-related lockdowns. Even when lockdowns decrease, most of the supply chain operations remain interrupted as organizations continue to operate in a reactive mode, attempting to recover first. Simultaneously, those companies and supply chains that survived and even thrived during the lockdowns agree that technologically driven systems were critical to their resilience and survival (8). As a result, corporations must urgently redesign their complete supply networks. A reassessment of supply chain operations and new systems is required to enable real-time digital monitoring of orders, automated tracking and alerts, route optimization, and increased navigational capabilities. While developing new systems, businesses must also consider the protection and support of the people who work in the logistics systems (8, 9). In addition, there is another urgent requirement for industry-wide technology adoption. The logistics industry's basic nature exposes it to the greatest dangers. As a result, the industry is undergoing a paradigm shift in terms of the very foundations of its operations. The new pillars of the logistics sector are contactless deliveries, location tracking, and early risk detection and segregation. All of which could be handled only via rapid technology integrations. The COVID-19 pandemic has hastened the shift to automated machines,' with the pandemic boosting long-term industrial trends like labor shortages, the increase of omni-channel distribution, and the advent of e-commerce (10). Due to disruptions in typical routines and staff dispersion, supply chains will see a significant degree of fluctuation in human resources whether drivers, warehouse staff, or others. Sustainability cannot be ensured just by technology, such as blockchain and robots. Combining logistics, inventory levels, demand projections, real-time visibility, and control over operations will allow system agility and rapid decision-making, including financial forecasting and resource allocation (11–13). The logistics sector in the post-COVID-19 period gives insight into boosting businesses and their operational flexibility via innovation and automation to become more resilient. The research was commissioned in response to ABB Robotics Company's worldwide survey of logistics and transportation industries, which revealed that 91.5% of respondents said that COVID-19 has influenced their operations. When the pandemic started in early 2020, businesses found themselves unexpectedly confronted with greater demand for a varied variety of products as a result of the substantial growth in online ordering and home delivery. Simultaneously, firms had to make up for personnel absences caused by self-isolation and social distancing techniques. As a result, businesses have been forced to adapt their operations, increasingly relying on robots and automation. Additionally, the paper underscores the industry's dramatic changes, arguing for a more rapid pace of technological adaptation. Logistics customers are acknowledging that implementing robotics and automation solutions can add significant value to their businesses by enabling them to respond quickly to changing consumer and market demands while also contributing to employee safety by reducing the risk of infection and automating riskier jobs. Even before the COVID-19 pandemic, both the retail and logistics industries were shifting away from traditional brick-and-mortar shopping as an increasing number of people rushed to the internet to make purchases. Between April 2019 and April 2020, internet sales in the EU surged by 30%, while the US, the UK, and China had comparable growth rates, resulting in an increased need for warehouse automation. By 2023, warehouse automation investments are predicted to expand at a CAGR of 12.6%, with particularly significant demand for piece-picking robots growing at a CAGR of 98.7%. Additionally, changes in global trade rules, the changing nature of customer demand for personalized goods, and the expectation of next- or even same-day delivery had already prompted forward-thinking operators to reconsider their strategies. Businesses may use technology and automation to assist their workforces, boost productivity, manage the transition to Omni-channel distribution, and profit from the expansion of e-commerce.

Technological Advancements in Industrial Logistics

A central hypothesis of the fourth industrial revolution (Industrie 4.0), holds that comprehensive integration of digitalization technologies into industrial firms' production and logistical processes leads to enhanced performance and/or cost savings, hence contributing to long-term development and the sustainable preservation of competitive advantages (14–16). Recent studies often differentiate between Industry 4.0 ideas and technologies (17, 18), as well as between an implementation-oriented ("digital transformation") and a technology-based ("digitization") viewpoint (19). However, there seems to be a lack of awareness of the potential for digitization projects in the particular field of industrial logistics inside industrial firms. Apart from communication devices, such a decision support system would need indoor positioning technology. Integrated Systems of this kind generate large amounts of data that may be analyzed in depth. Dynamic routing and enhanced scheduling will be provided in this cloud material handling system via the application of machine learning (ML) techniques (20). Recent research focusing on high-value products in the shipping industry has proposed an integrated model that combines lean principles with Industry 4.0 technologies. The proposed framework emphasizes the implementation of Radio Frequency Identification (RFID) technology for automated identification processes. To enhance physical security and safety measures, the model recommends the deployment of infrared barriers alongside anti-masking detection systems. The framework advocates for data centralization through a Software as a Service (SaaS) platform, utilizing a single interface for streamlined operations. This unified system manages multiple functions including access control, data encoding, and analytical processes. Furthermore, the research introduces an innovative sensor-based methodology designed to monitor and detect adverse environmental conditions that might impact product quality during transportation within the automotive supply chain. A few international logistics service providers were studied using a mix of literature research and case study techniques (21). Their purpose was to identify the obstacles to the effective digital transformation of logistic service providers. The study concluded with five issues inhibiting the digital transformation of logistics service providers and eight criteria for assuring successful digital transformation. Data protection and security breaches, as well as the complexity of the logistics network and underlying operations, were recognized as impediments to the digitalization of logistics service providers. The survey also emphasized the importance of employee and partner engagement, process standardization, data integration, and agile transformation management (21). Further, a literature study describes Industry 4.0 technologies now in use in manufacturing processes, as well as the implications of their use on logistics and supply chain operations. The study found that Industry 4.0 technologies like auto identification, additive manufacturing, and cloud computing have improved logistics operations, reduced network distribution distances, and optimized logistical resources (22). For instance, a study observed that pre-pandemic digital innovations were progressively adopted into real-world operations owing to variables including cost and time restrictions. At the onset of the COVID-19 pandemic, the extensive use of digital technology in Russia's transportation sector was examined. The findings suggest that the pandemic has accelerated the adoption of digital technologies and the digital transformation of the transportation industry (23). Research conducted during the COVID-19 pandemic highlighted how disease outbreaks can significantly disrupt global supply systems (24). While humanitarian logistics has been extensively studied, the analysis revealed that commercial supply networks remained vulnerable to epidemic-related disruptions. To address this gap, a six-phase control model was developed to enhance business supply chain operations during epidemics and pandemics. The research emphasized the critical need for digital transformation and long-term sustainability planning in supply chain management. Notably, the study identified a significant gap in academic literature regarding pandemic impacts on supply chain management, suggesting an opportunity for further research in this area (25). Analysis of the COVID-19 pandemic's impact on supply chains revealed significant vulnerabilities within traditional supply networks. These pandemic-exposed weaknesses provided valuable insights that can be used to develop more resilient, transparent, and sustainable supply chain systems (26). Despite its significance and global impact, the COVID-19 pandemic has not been thoroughly explored in the literature due to its recent emergence. Therefore, this article reviews the current literature on digitalization in industrial logistics within manufacturing businesses, focusing on a techno-economic perspective in the post-COVID-19 era.

Effect of Pandemic Disruptions on the Logistic Sector

The COVID-19 pandemic has significantly affected logistics companies involved in transporting, storing, and distributing goods. These firms play a key role in enabling businesses to deliver products to customers more efficiently and swiftly. Logistics providers are essential components of value chains, both domestically and internationally. As a consequence, pandemic-related supply chain interruptions in the business may have a detrimental effect on competitiveness, economic development, and job creation. Manufacturing disruptions in China send shockwaves across the global supply chain. Truck drivers were scarce at China's key container ports due to travel restrictions. Moreover, ocean carriers have canceled sailings. The ensuing shortage of Chinese components has a detrimental impact on industrial operations in other countries (27). The automobile and electronics sectors, as well as pharmaceuticals, hospital instruments, and consumables, as well as consumer items and services, were all affected throughout the world. Lockdowns and border restrictions were enforced as a result of the pandemic's global spread, greatly impeding goods delivery. The implementation of additional safety measures for warehouse staff, such as enforcing social distancing, contributed to bottlenecks in product transit. For instance, when Poland closed its border with Germany in mid-March, trucks were backed up for 37 miles along Germany's A4 highway. Similarly, the International Organization for Standardization reported that India's border closures caused a truck driver shortage, resulting in over 50,000 containers being stranded at the ports of Chennai, Kamajarar, and Kattupalli (13, 28). A second demand shock is expected to arise from the economic recession. Ongoing research is trying to determine the exact extent to which this pandemic may affect global supply networks. Due to logistics' exposure to trade, industry, and consumer demand for goods and services, the International Monetary Fund (IMF) anticipates a 3% worldwide downturn in 2020 (29). Supply chain interruptions and lockdowns have already impacted the logistics industry. Delivery delays, traffic congestion, and increased freight prices are likely as a result of operational difficulties. One mitigating factor is that record-low gasoline costs might bring some relief to transportation companies shortly. As a whole, the uncertainty will harm revenue generation. The term "logistics disruption" refers to a breakdown in the supply system, which has a detrimental effect on the SC's performance and consumer safety (30). The model includes threats and vulnerabilities as recognized risks. The COVID-19 pandemic, for example, is a disruptive occurrence that has wreaked havoc on the whole supply chain. Vulnerability refers to exposing a system in such a manner that it compromises and reduces the efficacy of adaptation and mitigation. Disruption of logistics at each stage of the process, and risk management necessitated decision-making: identifying risk and vulnerability sources, performing a risk analysis, and devising risk mitigation strategies (31). Transportation challenges arose from both internal and external disturbances. Internal disruptions refer to those impacting local suppliers and retailers, while external disruptions affect international shippers. These disturbances frequently lead to supply chain breakdowns in production, supply, and demand. For instance, the demand for car parts and goods has outpaced supply chain capacity due to pandemic-related disruptions. Likewise, the demand for various services has dropped sharply because of lockdowns in affected regions. Transportation challenges create a ripple effect throughout the economy, limiting mobility and causing further disruptions in production, distribution, and regular business activities (32). Manufacturing disruptions were defined as interruptions to internal operations caused by a shortage of raw materials or vehicle components during a crisis. Supply interruptions were defined as those caused by supplier inbound supply and shipping and supply market failures. Risks connected with unpredictable environments, demand complexity, changing client needs, and demand unpredictability all impacted logistics and transportation systems. Firms must use both short- and long-term risk management measures to prevent disruptive risks such as the COVID-19 disaster.

Conventional Supply Chain and Issues

The COVID-19 pandemic has wreaked havoc on global supply chain networks in ways that have never been seen before. In the face of increasing commodity costs, transportation delays, and port congestion, as well as evolving consumer behavior, manufacturers across all industries are being forced to deal with a variety of issues (33). Due to a long-standing focus on optimizing supply chains to minimize costs, lower inventories, and increase asset efficiency, many organizations have become unaware of the vulnerabilities in their supply chain connections to global disruptions, as demonstrated by the COVID-19 pandemic. Several firms have said that the COVID-19 pandemic has prompted them to take a close look at their internal systems and business strategies. Some areas have seen increased innovation, development, and competitive advantage in the wake of the pandemic, while others have seen a reduction in these factors. The potential of linked, digital supply networks (DSNs) to allow companies to predict, perceive, and adapt to unforeseen changes has been established, with the effect of these changes being minimized in the process (34). Emerging supply chain technologies are set to significantly enhance visibility across the entire end-to-end supply chain and improve companies' ability to withstand large-scale disruptions. DSNs are transforming the traditional linear supply chain model by breaking down functional silos and connecting businesses to their entire supplier network. These networks enable full visibility, collaboration, agility, and optimization across the supply chain. Leveraging advanced technologies like IoT, AI, robotics, and 5G, DSNs help foresee and manage future challenges. Companies that adopt DSNs will be better equipped to handle unexpected events, whether it's a "black swan" event like COVID-19, or other significant disruptions such as trade wars, armed conflicts, legislative changes, industrial disputes, demand surges, or supplier bankruptcies.

IoT, Big Data, and Blockchain Applications

The COVID-19 pandemic has led to considerable disruptions in daily life, driving technological advancements and innovation in the workplace. In theory, the IoT would involve a network of billions of interconnected devices capable of sensing, interacting, and exchanging data, which could be analyzed to provide valuable insights for planning, management, and decision-making. The IoT holds immense potential across various sectors, including healthcare, manufacturing, agriculture, telecommunications, and transportation. However, despite its widespread acceptance and the benefits it offers, IoT adoption has been slower than expected. Key reasons for this include (a) concerns around security, privacy, policy, and trust; (b) organizational inertia, long capital investment cycles, and a shortage of skilled professionals to implement IoT effectively; and (c) a lack of compelling use cases that demonstrate a clear return on investment (ROI) in some industries (35, 36). Scientists, health professionals, and epidemiologists may use big data to gather a tremendous quantity of information that will aid them in making educated decisions about how to combat the COVID-19 virus. Such data might be utilized to track the illness on a global scale and in real-time, as well as to inspire medical innovation. It might help anticipate the impact of COVID-19 on a particular area as well as the entire population. In the process of researching and developing novel therapeutic approaches, it is beneficial. People may benefit from big data because it can identify potential sources and possibilities for them, which can help them deal with difficult circumstances. In general, this technology gives information that may be used to research disease transmission, mobility, and health monitoring and preventive systems (37–39). A transparent and efficient system (such as healthcare) to battle the COVID-19 pandemic may be built using trustworthy, verifiable, distributed, and tamper-resistant ledger technology, which can be achieved using blockchain technology. It is capable of establishing the first line of defense via the use of a network of linked devices. The adoption of blockchain technology by healthcare institutions to regulate and manage the supply chain of personal protective equipment (PPE) could play a crucial role in identifying PPE-related fraud. This technology can also help create a more resilient and secure supply chain for PPE (40, 41). The participating organizations may verify the validity of PPE and detect any signs of tampering with or poor management of PPE throughout its transportation using blockchain-based solutions. Blockchain technology is used to maintain all movements, ownership data, and changes that occur to PPE in a distributed ledger in an immutable and transparent manner. Blockchain technology can securely store data related to multiple stages of the COVID-19 vaccine process, such as (a) development, (b) production, (c) certification, and (d) distribution to authorized immunization centers. Healthcare professionals can utilize blockchain in hospitals to verify, track, and validate vaccination data before administering vaccines to patients, ensuring greater transparency and accuracy in the immunization process (42). It may also be utilized for real-time notification management via the use of lightweight smart contracts, which are easy to implement. As a result of smart contracts, it will be possible to identify vaccine-related frauds early on, guarantee zero downtime, and remove the need for third-party services to manage COVID-19 vaccine logistics (43, 44).

AI and ML

To enhance the understanding and treatment of COVID-19, AI stands out as one of the most promising technologies in healthcare. AI applications, including machine learning, deep learning, natural language processing (NLP), and computer vision, can accelerate the development of effective solutions by analyzing large datasets related to the current outbreak. These applications encompass AI-driven clinical data analysis, robotic and remote surgeries, research and drug development, as well as the automation of healthcare tasks, procedures, and management processes. It gives an in-depth examination of various AI methodologies to better comprehend and describe the COVID-19 pandemic issue, among other things (45). For both infectious and non-infectious illnesses, AI and ML technologies are being applied to increase the accuracy of prediction. Medical specialists in numerous communicable illnesses (SARS, EBOLA) and noncommunicable diseases (Cancer, Diabetic) outbreaks are supported by recent research on the potential of ML/AI. One of the most significant types of AI is ML, which has applications in a variety of settings in health care, including identifying patient characteristics, predicting treatment methods, and precision medicine. In addition, DL or neural network models, which are employed in clinical data analysis and the diagnosis of specific illnesses, are examples of composite variants of ML (45). To improve the diagnosis and screening processes for identified patients, radiological imaging technologies such as computed tomography (CT), X-rays, and clinical blood sample data are integrated with machine learning and AI. The COVID-19 pandemic has been positively impacted by ongoing advancements in AI and machine learning, which have enhanced treatment, medication, screening, prediction, forecasting, contact tracing, and the drug and vaccine development processes, while also minimizing the need for human intervention in medical practice and reducing mortality rates. However, many of these models have not been sufficiently tested in real-world scenarios to demonstrate their effectiveness, yet they remain valuable tools in the fight against the SARS-CoV-2 outbreak (46, 47).

Literature Search Strategy

The investigation commenced with the selection of relevant keywords and datasets. The authors utilized the Scopus database for their analysis, as it offers a comprehensive range of articles suitable for examination. The primary keyword for the search was "logistics," which was subsequently expanded to include "IoT," "Big Data," "Digital Twin," "AI," "ML," "Blockchain," and "Industry 4.0." This search strategy was focused on the title, abstract, and keyword fields. The search was constrained to publications from 2020 to the present. The authors included only articles published in English and excluded review articles to focus on primary research that presents original empirical findings, novel methodologies, or direct implementations of technological solutions. This decision was made to capture first-hand evidence and concrete applications rather than summarized or secondary analyses, ensuring the analysis reflects actual implementation experiences and outcomes in the field. Conference papers were retained due to their contributions of cutting-edge research findings and practical applications that might not yet have reached the journal publication stage. Conference papers were incorporated due to their innovative contributions and the latest research findings presented in their proceedings. The following search string was employed: TITLE-ABS-KEY (LOGISTICS AND COVID AND DIGITAL) OR TITLE-ABS-KEY (DIGITAL AND LOGISTICS AND TECHNOLOGY) OR TITLE-ABS-KEY (INTERNET AND OF AND THINGS) OR TITLE-ABS-KEY (BIG AND DATA) OR TITLE-ABS-KEY (TECHNOLOGY AND SARS COV) OR TITLE-ABS-KEY (BLOCK AND CHAIN) OR TITLE-ABS-KEY (INDUSTRY 4.0). This search was limited to publications in English and only included papers published after 2019. The search strategy targeted the title, abstract, and keyword fields, initially yielding 23,338 potentially relevant papers. Following a systematic screening process, duplicate removal reduced the dataset to 10,816 articles. A thorough title and abstract screening further refined this to 183 relevant articles, from which 117 were selected for full-text review. The selection process then applied specific exclusion criteria, removing articles in other languages (21), those with insufficient data (41), comments (17), and letters (15). This rigorous screening process resulted in a final dataset of 23 articles meeting all inclusion criteria. This methodological approach ensured a thorough and systematic review of the literature while maintaining transparency in the selection and analysis processes.

Findings and Trends from the Literature

As a result of COVID-19, the articles on technology adaptation in the logistics sector have been embraced and eliminated as shown in Figure 1. There is a progressive increase in the number of publications being produced, particularly in the years 2020 to 2022. The proportion of different types of publications and datasets that were disseminated was calculated and indicated in Figure 2. Conference papers accounted for 23% of the total number of Publications published. Following COVID-19, the number of published sources relating to technical advancements and adaptations is shown in Table 1 below. Elsevier and Springer Link have the most number of articles in the fields of AI, machine learning, and blockchain technology. The use of IoT, blockchain, and AI has resulted in a progressive growth of technology. As a result of the research, it was discovered that IoT-assisted blockchain, AI, ML, and big data were used to improve conventional supply chains and challenges.

Table 1: Overview of Publications on Technological Adaptation in the Logistics Sector Post-COVID-19

Publication Source	No of Articles	Technology (Research Area)	Reference
The International Journal of Logistics Management	2	Digital Transformation, Logistics service Providers, Technology Adoption, AI, Blockchain.	(21, 48)
International Journal of Information Management	2	Digital Adoption; Supply chain network; Digital disruption;	(23, 25)
Journal of Advanced Transportation	1	Development of Port system dynamics model, COVID-19 pandemic stimulation.	(27)
Elsevier	4	COVID-19,Machine learning, AI, Pandemic	(3, 4, 18, 30)
Springer Link	4	Blockchain and its applications during pandemic	(7, 39, 43, 49)
Modern supply chain research and application	1	COVID-19, resilience, supply chain management, sustainable consumption, supply chain engineering.	(9)
Advances in Social Science, Education, and Humanities Research	1	Digitalization of labor, digital innovation, logistics, logistics outsourcing, logistics providers	(1)
Research in Globalization	1	COVID-19, MSMEs, Crisis, Policy, recommendations, Business survival.	(10)
Sustainability	2	Block chain, Information management, Sustainability	(11, 12)
Journal of cleaner Production	1	Industry 4.0, Challenges, Ethical and sustainable, business, Circular economy.	(14)
International Journal of Innovation Studies	2	Technology implementation, Survey, and Factors related to the implementation of I 4.0 technology.	(16)
Computers in Industry	1	IoT, Cyber-physical systems (CPS), Small and medium-sized enterprises (SME), Technology acceptance model (TAM).	(17)
Computers and Operations Research	1	Agricultural supply chain, Machine learning, Sustainability	(20)

Effects of the Current Pandemic on the Logistics Sector

As a consequence of the worldwide pandemic caused by the COVID-19 virus, about 90% of the world's population is subject to some sort of international travel restrictions. In turn, this has slowed travel demand and had serious consequences for airlines, prompting several to go into voluntary administration. Regardless, the virus provides opportunities for some while providing challenges for others. Several high-growth businesses have emerged as a consequence of the Coronavirus outbreak, including e-commerce logistics, on-demand services, and last-mile deliveries. A sharp decline in demand has been seen in industries such as the automobile industry, gasoline distribution, construction, and steel manufacturing. Both supply and demand shocks have impacted those heavyweight industries, making recovery a long and torturous process. Companies in landlocked and small island countries are also facing substantial production halts due to a lack of necessary inputs and raw materials to keep their operations functioning. Countries, particularly those with excellent road connections, are putting in place mechanisms to guarantee that commerce continues and that commodities reach their destinations while minimizing the effect on the whole supply chain. In times of economic uncertainty, the transportation and logistics industry is especially susceptible. In light of commercial shipping accounting for approximately 80% of global trade volume, companies are striving to meet rising demand while adjusting their service portfolios. TI CEO Manner-Bell notes that "more diverse logistics organizations have the potential to reallocate resources from one business area to another." Although there is an anticipated recovery in demand for logistics services following the coronavirus crisis, shipping industry volumes are projected to decline by 20 to 25%. To mitigate potential economic disruptions, several airlines are adapting their passenger aircraft to function as cargo planes.

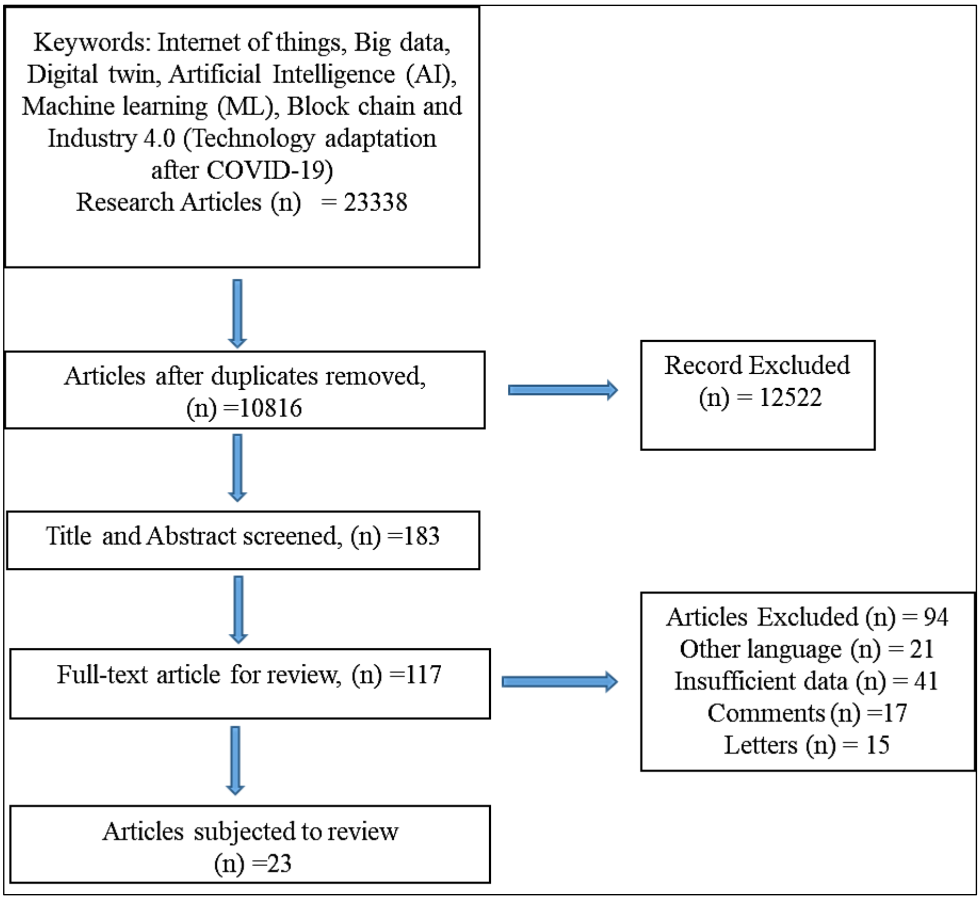

Figure 1: Systematic Process of Selecting Articles for Review

Figure 1 illustrates the systematic process of selecting articles for review. A total of 23,338 research articles were identified through keyword searches on digitalization technologies in logistics post-COVID-19. After removing duplicates, 10,816 articles remained. Screening the titles and abstracts reduced the selection to 183 articles. Following a full-text review, 117 articles were excluded due to language barriers (21 articles), insufficient data (41 articles), being comments (17 articles), or letters (15 articles). Ultimately, 23 articles met the inclusion criteria and were subjected to detailed review.

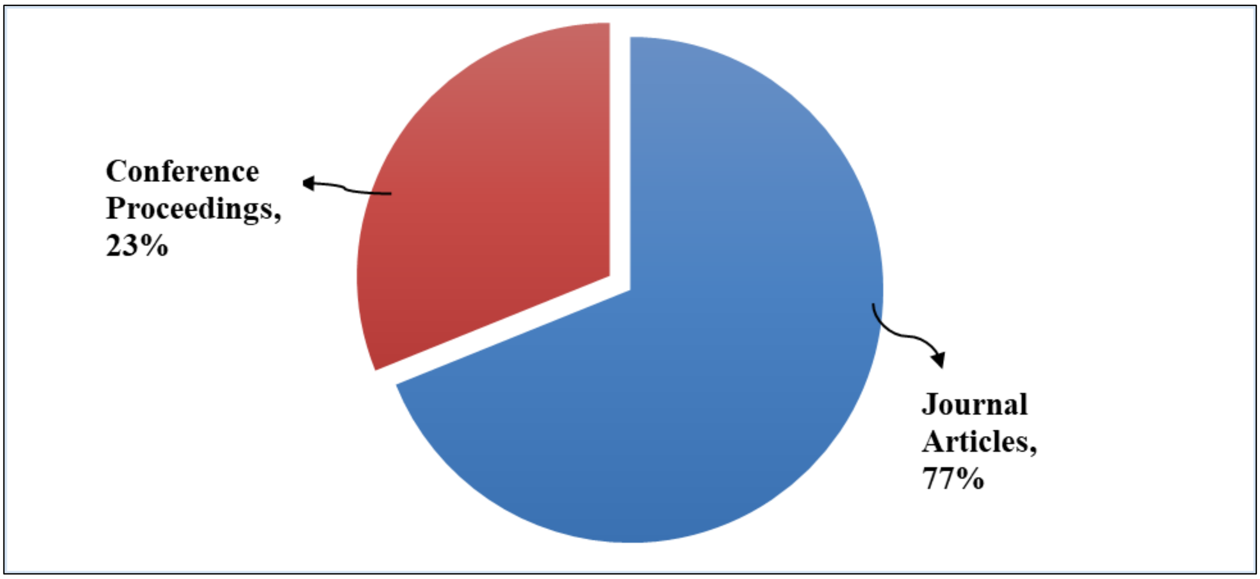

Figure 2: Pie Chart for the Distribution of Sources Included in the Review

The pie chart in Figure 2 illustrates the distribution of sources included in the review, with 77% from journal articles and 23% from conference proceedings. Review articles were excluded from the analysis.

Supply-chain Integration and Sustainability

Because of the COVID-19 pandemic, there is a demand-supply mismatch that is affecting global and local supply chains throughout the globe. When governments imposed limitations on international commerce owing to pandemic breakouts all around the globe, including lockdowns, quarantine restrictions, and border controls, international trade decreased by 12-33% (50–52). COVID-19 has had an impact on more than a thousand Fortune 500 organizations (53, 54). Although there are several risks to consider, supply systems may be made more resilient very fast (55). However, empirical research on the robustness and resilience of supply chains would give more in-depth insights into how those who are impacted or who are anticipated to be affected would deal with the risks presented by the COVID-19 directive. Such research would also give guidance for implementing preventive techniques to limit the negative effects of the pandemic on the supply chain, which would be very beneficial (56). Similarly, supply chain managers are focusing on implementing risk management strategies and enhancing supply chain resilience. There is a call for specialists to conduct empirical research on how suppliers are navigating challenges posed by COVID-19 to establish a sustainable supply chain (SSC). Global sustainability initiatives encourage businesses to adapt and reform their operations to address economic, social, and environmental issues, thereby maintaining strong buyer-supplier relationships through mutual coordination (57). The spread of the coronavirus has created a potentially life-threatening environment worldwide, exerting significant pressure on stakeholders, governments, and policymakers to sustain supply chains in light of social, environmental, and economic concerns (58). The COVID-19 pandemic has led to substantial disruptions in supply chain management globally, highlighting the need to identify, analyze, and prioritize the challenges affecting supply chain sustainability (SSC). In response to the pandemic, organizations are transitioning to a demand-driven model for managing their supply chains

(59). The relationship between the supply chain and environmental development forms the basis of supply chain sustainability (SSC). The COVID-19 pandemic has intensified pressure on enterprises that provide both material and intangible resources, prompting them to adopt new types of supply chains to address their needs. To balance demand and supply, companies are considering outsourcing intermediaries and leveraging the supply chain system's connections with numerous single-level suppliers (60). Because of the cooperation, the supply chain's efficiency has increased, while costs have been reduced and profits have increased. The bullwhip effect in supply chains may be decreased by retailers and suppliers working together to cut costs and increase efficiency (61, 62). The supply chains exist in a variety of forms and sizes, but they all contribute to the alleviation of the suffering of the people who are impacted. Both physical and intellectual assets are extensively shared, and the sharing of resources and information is essential for effective communication between suppliers and buyers, as well as between suppliers and buyers (63, 64). In past research investigations, supply chain vulnerability to disruptions was investigated in terms of the physical aspect, uncertainty concerns, and conceptual network analysis, among others. Supply chain feasibility is a combination of efficiency and long-term viability that improves the process's overall viability (65).

Technological Adoption and Challenges in Logistic Transformation

The global supply chain sector has responded to the problems of COVID-19 with vigor and quickness, safeguarding employees and consumers while adapting to seasonal and cyclical fluctuations in demand. Early on in the pandemic, the business-to-business logistics industry came to a near-complete halt. The ramifications were significant since supply lines were severely disrupted and new rules were implemented almost immediately. Companies that implemented agile supply chain strategies during the pandemic reported a 40% faster recovery compared to their counterparts, emphasizing the critical role of digital tools in managing disruptions (66). As the road to recovery gets underway, some businesses are aiming to diversify and shift their distribution networks closer to home, with nations such as Mexico, for example, serving as alternatives to China for enterprises in the United States of America. As a result, the business-to-consumer sector has flourished as individuals who are trapped in their homes resort to the internet to obtain their essentials. Not only did the number of products transported increase, but the nature of the things shipped changed as well, with more people buying even the biggest purchases online. Because of this, logistics businesses have been forced to accelerate their development plans, swiftly expanding to operate seven days a week and making major expenditures in e-commerce, manpower, and infrastructure to meet demands. Even though operations have grown, deliveries for this side of the market have tended to have a lower return; considering that drivers and subcontractors are often compensated per stop. As a result, firms are under even greater and more severe pressure to come up with innovative solutions to increase delivery density while also lowering costs. In reality, firms of all sizes and types must improve their operations throughout the whole logistics landscape – with data and technology serving as crucial enablers. Better supply chain transparency is essential, and this may be achieved by collecting and exchanging data that allows items to be tracked in real-time from the place of origin to the ultimate destination. This information may originate from a variety of sources, including the operating and planning systems of logistics organizations, sensors in warehouses, pallets in transit, and telematics in trucks and ships (67). A recent report by Global Tech Insights reveals that the integration of blockchain technology into supply chain networks has enhanced transparency and reduced fraud by up to 25% (68). In recent years, logistics businesses have improved their ability to communicate with clients about the specific time of arrival and the ability to adjust delivery arrangements. There is more that can be done to optimize routes utilizing data than has been done thus far. Businesses may anticipate interruptions by obtaining a precise view of the status and location of a product at each stage. When external data sources (such as congestion or the environment) are integrated with machine learning, real-time route modification is possible. In the pharmaceutical industry, for example, sensors may be used to monitor package temperature in real time; if the temperature exceeds a certain threshold, an alarm may be generated and remedial steps conducted, resulting in less waste, cheaper costs, and more on-time deliveries. The dramatic decrease in the cost of sensor technology is hastening the adoption of intelligent supply chain solutions and the exploitation of data across a wide range of industries. Additionally, when integrated with sophisticated analytics and machine learning, organizations may utilize this kind of big data to monitor and improve their operations as well as forecast problems. The ability to properly monitor and change the flow of products to improve efficiency, as well as the ability to model complicated supply networks, allows them to share data and collaborate more meticulously with customers and other stakeholders (21, 39, 52). Logistics businesses have responded to the challenge of making delivery safer for their employees as well as their customers, and they are succeeding. Last-mile contactless delivery systems have been crucial in the industry's response to the COVID-19 outbreak, which began in 2015. Given that the last mile constitutes approximately 30% of total delivery costs, optimizing this segment has become increasingly important as retailers seek to minimize long-haul transportation and enhance last-mile efficiency. While the use of drones for delivery is gaining traction, their deployment remains hampered by local regulations and restrictions, resulting in a slow adoption rate (9, 23). The adoption of smart locker solutions for secure, convenient, and contactless pick-ups, on the other hand, is rising at an exponential rate. To put it another way, safety, and sustainability are essential commercial drivers for the sector, particularly given the urgency with which environmental concerns must be addressed. Connected technologies are being used by leading logistics organizations to gather and share real-time data to assist drivers in lowering their fuel use and driving more safely. Logistics providers will need to optimize and automate as much of their operations as possible while also working collaboratively with others to function securely, efficiently, and predictably (8, 69, 70). The safe and efficient flow of products is critical to the revival of economies throughout the globe as the world adapts to a new normal. Long-term risk management strategies, including supply chain coordination, intelligent transportation systems (ITS), Industry 4.0, vendor management systems, transparency in logistics, carrier relationship management, and digital supply networks, can assist organizations in recovering from and withstanding disruptive challenges. As logistics companies have enhanced their communication with customers, consumers have become increasingly aware of specific delivery times and the options available for modifying delivery arrangements (71, 72). There is much more that can be done to optimize routes using data. Logistics firms can anticipate any disruptions by acquiring a thorough view of a package's status and position at each step. When external data sources (such as traffic or weather) are connected with machine learning, routes may be changed in real-time. For instance, organizations that serve the pharmaceutical industry may employ sensors to continuously check package temperature; if it exceeds a predetermined threshold, an alarm may be produced and remedial action done, resulting in decreased waste, cheaper costs, and more on-time deliveries (39, 73, 74). Sensor technology has become much more affordable, leading to an explosion of intelligent SC technologies and data use. When paired with powerful analytics and machine learning, this kind of big data enables firms to monitor, optimize, and predict their operations. They are capable of carefully monitoring and adjusting the flow of commodities for maximum efficiency, and even simulating complex supply networks. Additionally, they may share information and work more directly with customers and other stakeholders. SC collaboration in supply chain movement, transit, and storage logistics operations. It promoted B2B and B2C partnerships to cut supply chain transportation expenses. This might aid businesses in improving supply chain transportation resiliency (75). To achieve synergy and recovery from disruptions, extensive collaboration between enterprises, suppliers, and consumers was required to share resources, information, and technology. Businesses may develop effective and efficient logistics and transportation systems by using information technology and other administrative tools for operations management and decision-making (76, 77). ITS is the collection, communication, calculation, decision-making, and management of vehicle and transportation movement via the integration of multiple information systems. Effective transportation system management relies on various technologies, including the internet, electronic data exchange, wireless communications, computer technology, programming, and methods for acquiring and analyzing critical data. ITS also offers collaboration tools and a robust transportation management platform. ITS serves multiple functions, such as electronic toll collection, highway data collection, traffic management systems, vehicle data collection, transit signal prioritization, and emergency vehicle preemption. These technologies may be able to assist businesses in building more resilient transportation networks and increasing efficiency in the face of transportation disruptions. Numerous methods were used to manage road congestion, freight fleets and automobiles, infrastructure management, and communication between disparate components. For system operations and personal contextual mobility solutions, Generation 4.0 ITS included multimodal systems such as personal mobile devices, cars, infrastructure, and information networks. Industry 4.0 logistics and transportation systems should also be embraced and integrated by businesses. Logistics 4.0 refers to merging logistics with innovations in cyber-physical systems and applications. ITS and resource planning are two examples of technology applications that must be implemented in a logistics 4.0 system that is both reliable and efficient (78–80). These applications have the potential to increase transportation agility and flexibility while decreasing disruptions. Flexibility, agility, and redundancy have increased supply chain resilience (81). A TMS is a must-have tool for logistics 4.0 to perform efficiently. Logistics 4.0 makes use of real-time and in-line data to improve efficiency and effectiveness. To reliably detect autos on the road, track freight movement, negotiate with carriers, consolidate shipments, utilize the platform's advanced functions, and link with ITS, a TMS system was required. Furthermore, Vendor Control System Vendor-managed inventory (VMI) has proven to be successful for Wal-Mart and other retailers. Suppliers, manufacturers, distributors, and retailers may all benefit from VMI's knowledge and collaboration. The VMI idea sent data (inventory level and demand data) electronically across chain members, potentially allowing upstream and downstream parties to understand the transit disruption. It might also help with the analysis of transportation-related demand and supply disruptions (82–84). Manufacturers may use EDI to monitor distributor stocks and determine distributor requirements. The supplier may use EDI to look at the manufacturer's raw material stocks and make business decisions. Supply chain partners want visibility into supply chain freight operations when faced with a disruption risk such as COVID-19. During a crisis, transportation systems can leverage advanced supply chain visibility technologies to quickly adapt to changing circumstances. Enterprises must analyze real-time strategic information, including traffic patterns, weather conditions, and road and port statuses, to adjust demand, reroute supplies, and optimize delivery routes. Interestingly, non-integrated supply chains have been found to perform better than fully integrated ones. The implementation of IoT sensor technologies has significantly enhanced shipment tracking capabilities. For instance, IoT sensors can be placed on packages to monitor commodities, vehicles, and equipment within warehouses. Additionally, IoT-enabled container management has streamlined operations by improving fuel efficiency, facilitating preventative maintenance, and enabling proactive rather than reactive container management (85, 86). In light of this, IoT and logistics companies should collaborate to recover and mitigate the consequences of transportation interruptions during a crisis. When shippers, providers, and carriers work together as a team to manage cost and performance, long-term outcomes may be improved. Customer Relationship Management (CRM), may assist everyone in seeing problems from a fresh perspective, as well as the team in conceiving and exploring shared solutions. Carriers, for example, need longer lead times when capacity is limited but predictable. Client expectations for same-day pickup, quick delivery, and personalized service may require shippers to work under tighter deadlines. In a traditional competitive environment, these two sets of requirements are mutually incompatible. Each person would be arguing, accusing, and adhering to his or her beliefs. Shippers and carriers should collaborate these days to find common goals, complementing needs, and practical solutions that benefit both sides. This might help firms cope with disruptive threats such as COVID-19 (87, 88). To cope with today's volatile market, most organizations lack supply chain insight and adaptability. Through digitally connected information and transportation networks, the DSN refers to the firms' unconstrained real-time visibility. Lack of visibility, sluggish response times, conflicting objectives, and insufficient risk management are all issues that DSNs can assist with. DSNs must be developed rapidly, with scalability, intelligence, and adaptability in a networked environment. Developing extensive data analytics abilities might help businesses react more effectively to disruptive threats. Using DSNs and traditional supply chains may help increase talent, physical, financial, and information integration, as well as stimulate collaboration and open communication between upstream and downstream suppliers. These procedures might help businesses avoid transportation interruptions during the COVID-19 crisis (89).

Future Research on Technological Inclusions for Logistic Transformation

The advancement of technology is reaching the boundaries of what is possible and altering the way business is conducted. Today, it has become customary to have everything available online and at fingertips for fast access to information. Improved technology has also enhanced productivity in the supply chain, lowering costs and reducing the number of mistakes made. These advancements are beneficial to all aspects of the logistics business, including global transportation (by road, sea, and air), supply chain management, and cargo tracking and observation, among others. Here are some major technological breakthroughs that will have a significant impact on the future of the logistics business:

Real-time Tracking

In the past, consumers would place orders for shipments, receive an estimated arrival date, and then remain uninformed until contacting the company for updates. However, advancements in internet and software technologies have enabled access to shipment tracking systems at any time, day or night. This not only enhances the customer experience but also saves organizations valuable time and money in the short term. Shapiro, for example, offers its clients Shapiro 360°, a tailored system that allows them to monitor and manage shipments effectively. This system features shipping alerts, customizable reporting, and customer profiles that provide relevant information about each client's cargo. With these technological advancements, shipments can be tracked from the comfort of homes, leaving little room for complaints (90).

IoT

The IoT and RFID are ideas that have recently gained popularity. The IoT brings various advantages to the supply chain, including the possibility of saving costs and delays by removing dangers from the supply chain. For example, sensors installed in trucks, cargo ships, trains, and other vehicles work with alarm systems or dispatchers to monitor and record vehicle movements. This sensor technology processes and transmits information to crews, providing insights into potential threats and enhancing situational awareness. While the IoT is not a new concept, it continues to significantly influence the future of logistics by enabling more precise in-transit visibility and package delivery.

RFID

RFID technology, which has been in use for several years, is increasingly popular among businesses for inventory management, allowing both time and money to be saved. In this system, a tag or sensor is affixed to the goods, and radio waves are emitted from the device. The data is then received and processed by the company in subsequent steps. Although barcodes and RFID tags may appear similar, RFID tags offer faster data transfer and processing capabilities, making them highly attractive to businesses. Many organizations have already begun using RFID tags in distribution warehouses to monitor the containers stored there. Industry leaders in sectors such as apparel and large theme parks have also adopted RFID technology for operations.

Autonomous Delivering System

The future of transportation is moving toward management by technology, with journeys from point A to point B facilitated by computers or packages delivered by flying drones. While this might sound like something out of a science fiction movie, it is becoming a reality. Autonomous vehicles are already operational, and self-driving trucks are on the horizon. Companies like Embark and Uber have already conducted long-distance deliveries using autonomous technology, and Tesla plans to launch its self-driving truck later this year. This represents a significant leap forward in delivery processes. Amazon Prime Air aims to introduce a drone delivery service that would deliver products directly to customers' doorsteps in the future. While the idea of eliminating the wait time within the conventional four-hour delivery window is appealing, regulatory hurdles and high costs may delay widespread adoption.

Global Positioning System (GPS)

There was a time when instructions had to be printed from computers and carried along when leaving home. Almost everyone currently uses GPS, whether it is built into cars or available via mobile phones. The accuracy of these devices has increased dramatically over time, helping not just dissatisfied and lost drivers, but also the entire supply chain. Using GPS to monitor truck positions and improve hauls via access to up-to-date traffic data boosts efficiency and customer satisfaction, resulting in happier customers and more revenue.

Social Media

In the logistics industry, the use of social media is assisting in improving the company's overall operational efficiency. This platform has emerged as the most convenient and effective method for businesses to engage with consumers in recent years, allowing urgent information, industry news, and client feedback to be provided in real-time. According to a study conducted by Hootsuite, 59% of Americans who use social media believe that communicating with customer service via social platforms has made it simpler to get problems and complaints resolved quickly. For instance, Shapiro uses communication channels such as Facebook, Google, and YouTube to provide news and updates to its customers. Staying current with the latest technology is critical for maintaining competitiveness and enhancing productivity in the workplace.

Conclusion

The objective of this research was to synthesize prior literature on logistics and technology applications while examining the measures taken during the pandemic to mitigate supply chain disruptions. Despite progress, several issues remain unresolved, such as the effective integration of multiple technologies to maximize benefits. Current research has only partially explored the application of blockchain, AI, machine learning, and cyber-physical systems, underscoring the need for further studies in these areas. Additionally, there is a pressing demand for digital decision-support tools tailored for logistics, particularly during crises like pandemics, to enhance resilience and adaptability. The high cost of vendor monitoring discourages retailers from adopting new and innovative suppliers, while manufacturers are motivated to invest in advanced automation for long-term supply chain improvements. Digitization offers significant benefits, such as reducing avoidable waste and enhancing operational efficiency. Real-time data is critical for optimizing freight routes and distribution planning, which can substantially minimize distribution losses and lower costs. Moreover, combining real-time data with sustainable practices enables businesses to reduce their annual energy consumption significantly. Future research should focus on advancing digitization and developing comprehensive traceability systems to ensure advocacy, sourcing integrity, and safety, particularly during crises. Such systems can help combat counterfeiting and adulteration, which often increase during emergencies. Digitization also facilitates reliable audit trails, empowering suppliers to evaluate and improve product quality throughout the supply chain, from production to retail. Further investigation into traditional procurement practices is needed to address customer expectations and misconceptions, while simultaneously educating consumers on the health and quality implications of sustainable delivery systems. Technology tools enhance supply chain resilience, minimize waste, and promote sustainability. The shift toward end-to-end business models driven by logistical innovations underscores the transformative potential of digitization. Supply chain safety and advocacy will improve, democratizing market accessibility and supporting experimental business models and products. According to the World Economic Forum, advancements in automation, operational efficiency, consumer awareness, and large-scale adjustments in food production and consumption patterns are now achievable. Implementing technological and logistical system transformations will require a paradigm shift in the roles and responsibilities of public sector stakeholders, especially in addressing evolving food demand. Collaboration protocols, such as horizontal integration, must be carefully defined to achieve sustainable supply chain practices. Supply chain networks are critical to economic growth, with interconnected systems exerting significant influence on one another. Policymakers should envision future scenarios that prioritize environmentally, economically, and socially sustainable logistics systems, driven by local and national perspectives, to achieve lasting change and widespread adoption.

Abbreviations

AI: Artificial Intelligence, B2B: Business to Business, B2C: Business to Consumer, CAGR: Compound Annual Growth Rate, CT: Computed Tomography, CRM: Customer Relationship Management, COVID-19: Coronavirus Disease 2019, DNS: Domain Name System, DSNs: Digital Supply Networks, EDI: Electronic Data Interchange, GPS: Global Positioning System, IMF: International Monetary Fund, IoT: Internet of Things, ITS: Intelligent Transportation Systems, ML: Machine Learning, NLP: Natural Language Processing, PPE: Personal Protective Equipment, RFID: Radio Frequency Identification, SC: Supply Chain, SSC: Sustainable Supply Chain, TMS: Transportation Management System, VMI: Vendor Managed Inventory.

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Author Contributions

Claran Santhiyagu A conducted the literature review and drafted the manuscript. Vengadesh S contributed to the editing of the manuscript. Rajan Chinna P supervised the project, provided critical revisions, and approved the final version for submission. All authors reviewed and approved the final manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest.

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