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Impact of Artificial Intelligence in Building Supply Chain Resiliency

Priyank Kumawat

Supply Chain and Operations Management Professional
Oxnard, CA 93036, USA
kumawatpriyank@gmail.com

Abstract— **Supply chains are frequently exposed to disruptions, which can be either positive, driven by technological advancements, or negative, caused by natural and man-made disasters. This study aims to explore the possibilities and implications of building supply chain resilience through AI-driven AR/VR simulations. In light of the disruptions experienced during the COVID-19 pandemic, there has been a growing interest among both researchers and practitioners in the role of digital technologies in enhancing end-to-end visibility within supply chains and their potential for boosting resilience.**

The study provides insights into how leveraging the dynamic capabilities of supply chains through AI technology can strengthen resilience. It offers a forward-looking perspective on how emerging technologies will shape modern supply chains and play a crucial role in improving their resilience. The article underscores the transformative potential of AI, highlighting its ability to equip supply chains to better withstand disruptions and mitigate associated risks.

Keywords— *Supply Chain, Supply chain resilience, AI, Technology, Artificial Intelligence.*

1. Introduction

Over the past few decades, the use of mobile technology and the internet has seen tremendous growth and expansion. In recent years, the world has increasingly moved towards a digital future, with Industry 4.0 technologies being widely regarded as the way forward [1]. The application of modern technology has radically transformed nearly every aspect of our lives, including what we eat, our education systems, transportation, communication, entertainment, and even healthcare [2]. Digitization requires an economy to have access to high-quality internet, advanced scientific and technological capabilities, and broad access to information across various disciplines [3]. A key goal of these advancements is to create supply chains that are resilient, capable of withstanding disruptions regardless of their nature.

In the rapidly evolving fields of risk management and supply chain management, the concept of resilience remains difficult to define precisely [4]. The aim of this paper is to provide a comprehensive perspective on resilience by conducting an extensive review of existing literature, particularly in the context of technology, and to offer insights into the potential and implications of using artificial intelligence (AI) to build and sustain supply chain resilience. Additionally, this paper identifies existing gaps in the current research and sets the stage for further exploration in this area.

2. Literature Review

In simple terms, a supply chain refers to the entire set of activities involved in delivering a finished product or service to the end-user or final consumer. These activities typically include raw material procurement, transportation to manufacturing facilities for production, followed by the movement of the finished product to distribution centers or retail stores, from where it is ultimately delivered to consumers [5].

A supply chain is a carefully designed and synchronized network that encompasses every company, facility, and business activity involved in procurement, production, manufacturing, and delivery of products. Every business, globally,

relies on its supply chain to manufacture products and bring them to market for consumer purchase. Additionally, a business may serve as a critical link in the supply chains of other companies [6].

In today's era of globalization, supply chains can be both local and global in scope. Over the past decade, extensive research on supply chain management (SCM) has resulted in a wealth of scholarly literature. This study examines theories and data published in national and international journals from 2015 to 2024 (up to the present), along with other available resources such as government data, reputable business periodicals, and other reliable sources.

2.2 Modern Supply Chain

Over time, supply chains are constantly evolving in terms of size, structure, individual components, and their organization and interaction. These factors determine the coordination, control, and management of the supply chain system. Supply chains can range from mature and well-established networks that are relatively stable and robust, to emerging supply chains that are subject to significant change and development. New supply chains may emerge and evolve for a variety of reasons [7].

The current dynamics of business and the volatility of the business environment ensure that supply chains are intricately linked to the value chain and should not be viewed as independent entities. In today's highly competitive world, it is crucial that all elements of the supply chain be fully integrated to enable seamless, real-time, and instantaneous information flow [8].

2.3 Nature of Modern Supply Chain

A typical supply chain, whether directly or indirectly involved in satisfying customer demand [9], integrates various functions. These include product design and development, procurement of raw materials and components, demand forecasting, product launch planning, logistics and supply arrangements, sales channel selection, customer support, and providing visibility into order status [6].

2.3.1 Global
Modern supply chains are global and form an intricate network of various entities, including suppliers, producers, distributors, and customers, that connect multiple countries and organizations [10]. Despite challenges such as managing logistics across different regions, regulatory barriers, cultural differences, demand forecasting issues, and cybersecurity risks, global supply chains are essential for businesses to thrive in the global marketplace [11]. They enable businesses to coordinate key activities like procurement, manufacturing, distribution, and customer service, ensuring that goods and services are delivered efficiently and cost-effectively [12].

2.3.2 Complex
Contemporary economic trends, including globalization, have led to the emergence of highly complex and intricate supply chains. The design, development, configuration, interactions, efficiencies, capabilities, and management of these supply chains have become critical challenges for companies. As a result, supply chain management (SCM) is not only essential for competing effectively in modern markets but also for ensuring responsible practices throughout the entire supply chain [13].

2.3.3 Prone to Disruptions
Modern supply chains are increasingly vulnerable to unforeseen, unanticipated, and intensifying disruptions from countless sources. This is particularly true due to their global scale—events in one part of the world often have ripple effects that impact the entire supply chain. As a result, supply chain resilience (SCR) has become a critical concept that complements traditional risk management. On its own, the conventional risk management approach has proven inadequate in addressing unexpected disruptions, leading to severe consequences that affect supply chain performance and threaten business continuity [14]. The COVID-19 pandemic highlighted the extent of global interconnectedness, exposing vulnerabilities within the supply chain. Numerous bottlenecks emerged, disrupting the global network of firms, people, and transport systems involved in ordering, manufacturing, and delivering goods to warehouses, retail stores, or directly to customers' doorsteps [15].

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2.4   Prone to Disruptions

Modern supply chains have become increasingly vulnerable to unforeseen, unanticipated, and intensifying disruptions from a variety of sources. This is especially true given their global scope—events in any part of the world can have far-reaching effects on the entire supply chain. As a result, supply chain resilience (SCRes) has emerged as a critical concept that complements traditional risk management. On its own, the conventional risk management framework has proven inadequate in addressing unexpected disruptions, often leading to severe consequences that undermine supply chain performance and threaten business continuity [14]. The COVID-19 pandemic highlighted the extent of the modern world's interconnectedness, revealing vulnerabilities within the global supply chain. Multiple bottlenecks emerged, disrupting the complex network of firms, people, and transportation systems involved in the ordering, manufacturing, and delivery of goods to warehouses, retail stores, and even directly to customers' doorsteps [15].

2.5   Nature of Disruption

Disruptions to supply chains can be natural, such as weather conditions, floods, hurricanes, landslides, wildfires, or even disease outbreaks. The COVID-19 pandemic serves as the most striking example of a natural disruption, bringing global supply chains to a standstill and affecting nearly every aspect of normal life. Geopolitical events also have a significant impact on global supply chains [16]. Regulatory hurdles, such as sanctions, can limit access to raw materials, critical components, suppliers, and markets. For instance, sanctions on Russia have disrupted the global supply of oil and natural gas. Similarly, the rerouting of ships due to the Red Sea crisis, the Russia-Ukraine war, and unrest in the Middle East have all caused disruptions to global supply chains [17]. Technological disruptions typically occur when the systems that support the supply chain experience failures, vulnerabilities, or weaknesses. These disruptions can arise from various factors, including power outages, equipment breakdowns, and software glitches [18].

3.   Importance of Supply Chain Resilience

To manage the risks that arise over time, supply chains must be designed to respond efficiently and effectively, without negatively impacting business operations. They should possess the capability to recover quickly, return to their normal state, and resume operations after disruptive events, all while meeting customer demands [19]. This is the essence of supply chain resilience (SCR) [20]. SCR is a crucial discipline that focuses on integrating environmental and social considerations into supply chain practices, helping organizations achieve sustainability goals while minimizing the impact of disruptions. In sectors like healthcare, developing effective emergency preparedness plans is especially critical to ensure the continuity and availability of essential supplies during disruptions [21].
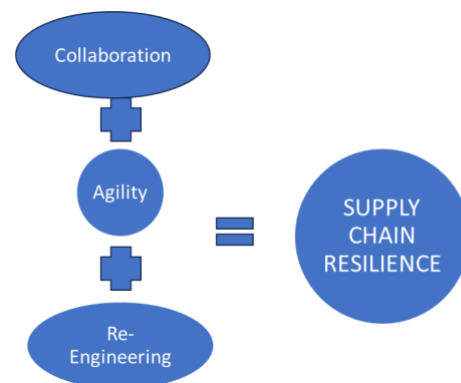

Figure 1: Modern Supply Chain Resilience

The ongoing digital revolution (i.e., Industry 4.0), coupled with global disruptions such as the COVID-19 pandemic, has significantly impacted supply chains [22]. Other persistent disruptions, such as extreme weather events, have further exposed supply chains to operational challenges. These disruptions manifest in various ways, including shifts in consumer purchasing patterns, changes in product demand, and the increasing need for greater flexibility and responsiveness in delivery logistics. Extreme weather conditions can also strain critical resources, such as power supplies needed for heating or cooling, which, in turn, can create shortages of materials for producers and require reactive measures to recover effectively [23].

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In recent years, these disruptions have affected the supply of vital materials, including steel and semiconductors, as well as essential consumer goods, such as toilet paper and baby formula, presenting significant challenges for global businesses. The impact is further exacerbated by technological advancements, labor market shifts, geopolitical tensions, and climate change, all of which add new layers of complexity and risk to existing business operations. At the same time, these challenges can also uncover new opportunities for business growth.

In such a disruptive environment, businesses often face immense pressure to meet customer demands consistently. However, this pressure is not solely negative. Successfully navigating disruption can position companies to capitalize on emerging market opportunities. To survive and thrive in this rapidly changing landscape, businesses must develop resilient supply chains with fully integrated digital operations, prioritize customer needs, and establish efficient, reliable, and sustainable delivery networks [24]. Achieving this is no easy feat. Companies that design supply chains capable of quickly responding to disruptions can not only mitigate risks but also seize opportunities to become more stable, robust, and competitive in their respective markets.

Artificial Intelligence (AI) offers a promising solution for enhancing supply chain resilience. However, the literature on AI applications in supply chain management remains fragmented, and there is currently no comprehensive decision-making framework to identify and apply effective AI techniques to foster supply chain resilience (SCR).

4. Enhancing Supply Chain Resilience Using Technology

Technology and communication play a critical role in both local and global supply chains, although their applications and significance vary. In international supply chains, advanced technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and blockchain are essential for managing complex global operations. These technologies facilitate real-time data exchange, enhancing visibility and improving coordination across the supply chain [10]. One of the major challenges in global supply chains is shipment tracking, a problem that becomes more pronounced during disruptions. Many existing supply chain data systems are inadequately equipped to support coordinated and verified tracking throughout the logistics cycle [25].

Studies have highlighted the crucial role of information technology (IT) in enhancing supply chain resilience (SCR). IT solutions, such as information-sharing systems that foster collaboration and visibility tools, play a pivotal role in improving responsiveness and reducing risks. Additionally, contemporary research is increasingly focused on emerging technologies, including IoT, blockchain, and AI, to further advance SCR and address the evolving challenges in supply chain management [20].

4.2   AI - the Champion

Among the most prominent technologies transforming modern supply chains, such as blockchain, IoT, and cloud computing, Artificial Intelligence (AI) is rapidly gaining attention. AI is defined as the capability of machines to communicate with humans and other machines, while also mimicking human abilities [26]. A series of disruptive events—ranging from labor shortages and the COVID-19 pandemic to natural disasters and geopolitical conflicts—have significantly impacted global supply chains. These disruptions have highlighted the growing risks associated with continuing the practice of outsourcing manufacturing [27]. As new vulnerabilities are exposed, it has become essential for companies to reassess their supply chain strategies. There is an increasing need to adopt forward-looking planning and forecasting techniques to ensure that supply chains are not only agile but also resilient in the face of unforeseen challenges.
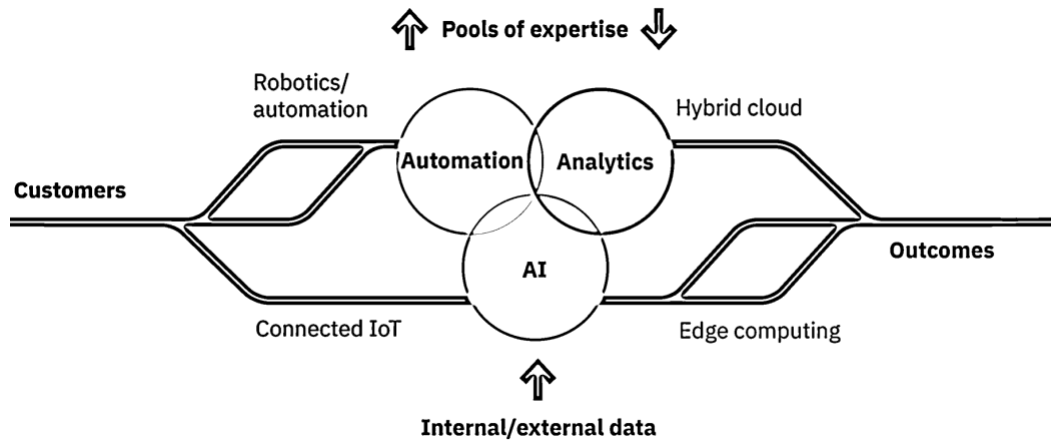
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Figure 2: Supply Chain Resilience Using AI Workflow

Modern cutting-edge technologies like Artificial Intelligence (AI) offer unique opportunities for reshaping supply chains by positioning production closer to markets, reducing dependencies, and achieving competitive cost efficiencies. AI can be leveraged for real-time shipment tracking, providing visibility into the status, location, and estimated delivery time of shipments. AI-powered tracking systems can proactively identify emerging issues and potential delays, while optimizing delivery routes and schedules [28]. Furthermore, AI is increasingly replacing traditional spreadsheet-based analytics, which were historically used to manage and optimize supply chain operations. For example, AI-driven forecasting significantly reduces the occurrence of errors that often led to substantial sales losses and product unavailability, thus impacting the entire supply chain ecosystem [27].

AI is a powerful tool for enhancing supply chain resilience by supporting business continuity. It offers a wide range of applications in process intelligence [29], enabling companies to handle disruptions caused by external conditions effectively. However, to maximize the benefits, the technology must generate actionable insights. By combining AI-driven insights with human expertise, organizations can create a blueprint for change management, transforming their operational models into more resilient and adaptable frameworks.

A study by Belhadi et al. [30] proposed an integrated Multi-Criteria Decision-Making (MCDM) approach, using AI-based algorithms such as fuzzy systems, Wavelet Neural Networks (WNN), and Evaluation based on Distance from Average Solution (EDAS), to identify patterns and help develop diverse strategies for building supply chain resilience (SCR). The analysis revealed that

need systems hold the most promise for promoting SCR strategies. However, only a few studies offer an integrated decision-making framework that can guide practitioners in effectively deploying AI to strengthen supply chain resilience.

4.3 Use of Simulations

Sophisticated AI technologies, such as advanced analytics-driven forecasting, digital twin simulations, and supply chain optimization tools, are increasingly enabling companies to strike a better balance between efficiency and resilience in their value chains. These AI-driven solutions are adept at managing complexity, helping organizations navigate transitions and transformations, mitigate risks, and drive value creation. Additionally, Augmented Reality (AR) and Virtual Reality (VR) simulations are proving valuable in supply chain management (SCM) by enhancing efficiency, reducing errors, and improving safety. By leveraging AR and VR tools, supply chain managers can access real-time views of any site, whenever necessary, to ensure that operations proceed according to plan. This capability is particularly critical during natural disasters or other disruptions when key personnel may be unable to be physically present on-site, ensuring continuity and minimizing the impact of unforeseen events on the supply chain.

4.3.1 AR Technology
Augmented Reality (AR) superimposes computer-generated data, such as images, sounds, or other sensory information, onto the real world, enhancing the user's perception by layering digital elements onto their environment [31]. DHL, for instance, employs AR technology to streamline the order picking process while reducing errors. Employees use smart glasses to view the exact location of items in the warehouse, helping them

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efficiently place products in the correct carts. These smart glasses also display the picking list within the employee's line of sight, ensuring they can follow the most efficient route through the warehouse [32]. By integrating AR with AI technology, DHL can facilitate faster product movement without requiring extensive training. New employees can also engage in simulated supply chain scenarios - such as machinery handling in a warehouse or logistics management in a virtual control room - thanks to AR's interactive capabilities [31].

4.3.2   VR Technology

Virtual Reality (VR) can significantly enhance the delivery aspect of the supply chain. Delivery drivers are tasked with ensuring timely product deliveries to distribution centers, stores, homes, and offices, often under specific conditions, such as temperature control. Time is of the essence in these situations, and VR can provide substantial support. By overlaying important information directly onto the driver's windshield, VR enables drivers to avoid relying on handheld devices for navigation. This helps them identify alternate, shorter, and more efficient delivery routes in real time, improving the overall efficiency of the delivery process [32].

AI technologies help balance efficiency and resilience by incorporating uncertainty into simulations that mirror real-world scenarios. These AI-driven simulations allow organizations to assess potential risks, explore alternative scenarios, and make informed decisions. AI also generates optimal plans for various time horizons, balancing costs with revenue while providing real-time, end-to-end visibility. This helps organizations anticipate and respond to disruptions more effectively [33].

4.4   Increase Visibility

AI plays a pivotal role in improving internal operations, starting with achieving enhanced supply chain visibility. Visibility refers to the ability to track and trace inventory as it moves through the supply chain, enabling firms to respond to disruptions in real time. A 2021 survey revealed that only about 2% of companies had visibility beyond their tier-II suppliers—those providing resources and components to their direct suppliers. Without strong visibility, companies' supply chains become vulnerable to disruptions from various factors such as natural disasters, geopolitical tensions, trade barriers, pandemics, and product recalls [34]. Therefore, leveraging AI to improve supply chain visibility is crucial for ensuring resilience.

Visibility is often considered both a capability and an outcome. From a capability perspective, it refers to the ability to represent a physical supply chain in a digital format, supported by real-time data that can be accessed, processed, and updated to aid planning, monitoring, and decision-making. As an outcome, this capability manifests as end-to-end supply chain visibility, often realized through the creation of a digital twin of the physical supply chain [22].

5.   Discussion

Supply chains are vital to the global economy and essential for modern life. In today's technological era, it is crucial to integrate supply chains and effectively manage the vast amount of data flowing through them. Properly harnessing this data can help identify weaknesses and address gaps, making supply chains more efficient and resilient. To speed up the movement of goods, reduce errors, and eliminate human inefficiencies, it's important to leverage technology without displacing significant volumes of labor or incurring exorbitant costs. While human involvement is necessary, it often introduces errors and biases, no matter how minor, which contribute to inefficiency in the system. To build a more resilient and efficient supply chain, understanding the lifecycle and evolution of the supply chain is essential. This understanding provides new perspectives and insights into designing and managing modern supply chains.

The current business ecosystem is highly volatile and chaotic, characterized by challenges ranging from natural disasters to global pandemics. This environment necessitates that supply chains be flexible and resilient to overcome various hurdles. The application of Artificial Intelligence (AI) in building resilient supply chains has proven to offer several advantages, including faster decision-making, shorter cycle times, improved operational efficiency, and continuous improvement. Early adopters of AI-enabled supply chain management have seen significant benefits, such as a 15% reduction in logistics costs, a 35% improvement in inventory accuracy, and a 65% increase in service levels [35].

As AI technology evolves, its role in enhancing supply chain resilience will continue to expand, directly impacting the survival and prosperity of businesses in the future. Gartner predicts that, within the next five years, the level of machine automation in supply chain processes will double, according to the expectations of supply chain

organizations [36]. This growing trend underscores the importance of adopting AI-driven solutions to strengthen supply chains.

This study aims to explore the challenges faced by global supply chain executives when adopting AI solutions to enhance supply chain resilience. It also seeks to contribute to the existing body of knowledge on the subject by examining how AI can influence the development of resilient supply chains. As AI becomes increasingly essential for competitive advantage, its integration into supply chain operations is shifting from being an option to a business imperative.

While some areas of information technology (IT) are being seen as basic competitive necessities, AI technology is rapidly emerging as a key differentiator in supply chain management [26]. Many organizations are progressing from simple remote monitoring to real-time control and optimization of operations, eventually transitioning to large-scale adoption of autonomous systems powered by AI. However, despite its growing importance, AI remains a strategic consideration for many companies, often hampered by organizational processes that act as barriers to its full adoption. This research also acknowledges the gaps in previous studies, particularly regarding the factors and challenges that influence AI adoption decisions.

5.2 The downside of AI driven SC

Undoubtedly, Artificial Intelligence (AI) has immense potential to enhance business agility and operational efficiency. However, the implementation and adoption of this technology in supply chain operations come with several challenges. While there is considerable enthusiasm for the integration of AI in supply chains, this excitement can sometimes overshadow the reality that AI is not a one-size-fits-all solution to every supply chain issue. Successful implementation of AI requires careful strategic planning and thoughtful execution. Without these, AI initiatives are likely to fail, potentially hindering progress rather than advancing it. In fact, a poorly executed AI strategy could set a company back significantly, resulting in costly and damaging consequences.

One of the key challenges in AI adoption is the difficulty in finding and retaining the right talent. AI professionals are in high demand, and companies must invest substantial time and resources into recruiting skilled individuals who can drive AI initiatives forward. However, the

investment doesn't end with hiring; companies must also focus on the continuous development and integration of these specialized talents into their supply chain operations [37].

Moreover, certain technologies like Augmented Reality (AR) and Virtual Reality (VR) are still in relatively early stages of development. While these tools show promise, they are not yet mature enough to deliver the consistent and sustainable results required for building highly efficient and resilient supply chains [38].

AI Supply Chain - Challenges [37]

- Securing & Retaining Right Talent
- Lack of Stakeholder Commitment
- Budget Constraint
- Data Inaccessibility
- Lack of IT Accecc
- Subsstandard Data
- Diversity of Data Sources
- Functional Silos
- Legacy Systems
- Static Structures
- Skill Gaps
- Ambiguous Transformation Strategies
- Short Term Optimization
- Moving from Poc to Production

The successful implementation of AI is heavily reliant on the availability and accessibility of vast volumes of data. AI and machine learning (ML) require organizations to rapidly ingest new data, integrating both structured and unstructured information into cloud-based systems. Without this data infrastructure, businesses will struggle to make accurate predictions, such as demand forecasting, and fail to derive actionable insights from their operations [39].

Inadequate data access can undermine the entire process. When data is fragmented or siloed, skilled, well-paid data professionals are forced to spend excessive time searching for relevant data, which impedes their ability to perform optimally. For AI to function effectively, it needs a comprehensive, integrated data set that provides a holistic view of the supply chain. Without this, AI systems lack the complete picture, reducing their potential to

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optimize and analyze processes efficiently.

The implementation of AI presents several challenges for freight forwarders. One key hurdle is selecting the appropriate AI technology that aligns with their specific workflows. Additionally, integrating diverse data sources and overcoming the steep learning curve of new technologies can be difficult. Ensuring robust data security and implementing necessary privacy measures are also critical concerns [28].

For successful AI adoption, companies often need to upgrade or modify existing legacy systems, many of which may need to be discarded altogether. This can require significant financial investment, which may be prohibitive for some businesses. Moreover, the introduction of AI can lead to employee resistance. The transition to AI-driven processes may alienate workers who are unwilling to adapt to new technologies. Furthermore, automation may displace employees whose tasks are replaced by AI, leading to dissatisfaction and potential unrest within the organization.

6.   Recommendations

Due to the constantly evolving nature of customer demands and the business environment, companies must align their business objectives with broader corporate goals to ensure superior customer experiences. This, in turn, influences their reputation and overall business sustainability, making it essential for enterprises to explore viable alternatives.

Combining Technologies

Common technologies like Radio Frequency Identification (RFID) tags and barcodes, while widely used for product identification, have limitations in data storage capacity and supply chain interoperability [21]. Although RFID and barcodes are not AI technologies, they can complement AI systems to enhance efficiency, supporting growth and expansion within supply chains.

Alternate Technology

The implementation of AI in supply chains can present various challenges. In this context, blockchain technology emerges as a promising solution, offering a platform for secure and transparent transactional records across multiple parties [40]. Blockchain enhances supply chain

resilience by enabling stakeholders to access accurate, real-time data for precise location tracking, product identification, and proper handling. This ensures the uninterrupted supply of critical inputs and services, contributing to more efficient and secure supply chain operations [41].

7.   Conclusion

In today's highly competitive and rapidly changing business environment, a resilient supply chain is crucial for companies to respond quickly and effectively to both global and local disruptions, while still meeting client expectations and delivery timelines. The significance of supply chain resilience lies in its ability to counteract disruptions, minimizing their impact on operations, revenues, and customer satisfaction. Furthermore, a resilient supply chain can provide a competitive advantage, helping businesses maintain operational continuity and adaptability.

This study contributes to a deeper understanding of the invisible networks of knowledge production in Supply Chain Management (SCM) and offers valuable insights that can influence both current and future research paradigms. It also emphasizes the need for exploring the potential of integrating various technologies to enhance AI's effectiveness and address its limitations within SCM contexts.

Existing studies on the application of AI in SCM lack a comprehensive, universal framework for identifying and implementing robust AI solutions across all supply chains. Given that no single solution fits all businesses, it is critical to recognize the uniqueness of each organization and its supply chain when crafting tailored strategies for building Supply Chain Resilience (SCR). This study lays the groundwork for future research and practical applications in this evolving field. Overcoming the challenges of implementing AI in SCM is a complex endeavor that demands careful strategic planning, significant investments in training, and a cultural shift towards continuous innovation to unlock AI's full potential.

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