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Managing risk and resilience in the healthcare supply chain. A literature review

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We are the people we've been waiting for

Out of the ruins of hate and war

Army of lovers never seen before

“We Are the People” by Martin Garrix featuring Bono and The Edge of U2

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LIST OF ACRONYMS

AFP	Alpha-Fetoprotein
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
ALPS	Agency for Logistics Procurement and Supply
API	Application Programming Interface
AR	Augmented Reality
BOT	Blood, Organs and Tissues (patient-derived products)
BWM	Best Worst Method
CA-DPPF	Certificate Authority-Decentralized Privacy-Preserving Framework
CoT	Chain of Things
CPS	Cyber-Physical Systems
DMDs	Drugs and Medical Devices (industry-derived products)
DoS	Denial of Service
DSS	Decision Support System
DT	Digital Technologies
EC-DSA	Elliptic-Curve Digital Signature Algorithm
ED	Environmental Dynamism
EHS	Environment, Health and Safety
EMA	European Medicines Agency
FDA	Food and Drug Administration
FFNs	Fermatean Fuzzy Numbers
FSE	Fuzzy Synthetic Evaluation
GAAD	Gender, Age, Alpha-fetoprotein, Des-γ-carboxyprothrombin

GALAD	Gender, Age, Lens culinaris agglutinin-reactive fraction of AFP, Alpha-fetoprotein, Des-γ-carboxyprothrombin
GNSS	Global Navigation Satellite System
GOA	Grasshopper Optimization Algorithm
GP	Goal Programming
GPR	Gaussian Process Regression
GPS	Global Positioning System
GRU	Gated Recurrent Unit
HBV	Hepatitis B Virus
HCC	Hepatocellular Carcinoma
HSC	Healthcare Supply Chain
HSCs	Healthcare Supply Chains
HSE	Health Service Executive
HSCR	Healthcare Supply Chain Resilience
IDP	Immutable and Decentralized Pharma
IHBN	Indian Herbal Blockchain Network
IoE	Internet of Everything
IoMT	Internet of Medical Things
IoT	Internet of Things
IPFS	InterPlanetary File System
IT	Information Technology
JIT	Just-in-Time
LMICs	Low and Middle-Income Countries
MABAC	Measurement of Alternatives and Ranking according to Compromise Solution
MASLD	Metabolic Dysfunction-Associated Steatotic Liver Disease
MCDM	Multi-Criteria Decision-Making Model

MILP	Mixed-Integer Linear Programming
ML	Machine Learning
MOQs	Minimum Order Quantities
mRNA	messenger Ribonucleic Acid
NAIBHSC	Novel Approach for Integrated IoT with Blockchain in Health Supply Chain
NTDs	Neglected Tropical Diseases
OECD	Organisation for Economic Co-operation and Development
OIPT	Organizational Information Processing Theory
PiF	Picture Fuzzy
PIVKA-II	Protein Induced by Vitamin K Absence or Antagonist-II
POS	Point of Sale
PoS	Proof of Stake
POTA	Proof of Trusted Authority
PoW	Proof of Work
PPE	Personal Protective Equipment
PSC	Pharmaceutical Supply Chain
R&D	Research and Development
RFID	Radio-Frequency Identification
SC	Supply Chains
SCM	Supply Chain Management
SCV	Supply Chain Visibility
SEM	Structural Equation Modeling
SLR	Systematic Literature Review
USG	Ultrasonography
WHO	World Health Organization

INTRODUCTION

The management of the healthcare supply chain has become a crucial element for the effective functioning of the global healthcare system. An efficient supply chain organization directly influences the accessibility, quality and efficiency of healthcare services, determining the ability of a system to respond promptly to the needs of patients and healthcare providers. In recent years, particularly following the COVID-19 pandemic, new challenges have emerged, highlighting the vulnerabilities of traditional supply chains**.** For instance, during the early stages of the pandemic, severe shortages of personal protective equipment (PPE) and ventilators exposed critical weaknesses in procurement and distribution networks, delaying the response of hospitals and healthcare facilities. Among the most significant issues are global supply disruptions, the increasing demand for critical resources, reliance on international suppliers and the necessity of implementing more agile and digitalized solutions to ensure operational continuity (Ivanov & Dolgui, 2020).

To address these challenges, the healthcare supply chain is undergoing a progressive integration of advanced technologies, including artificial intelligence (AI), blockchain and real-time data management. These solutions directly tackle supply chain vulnerabilities by improving forecasting accuracy, automating inventory tracking and enhancing transparency in procurement processes. Their implementation aims to reduce operational costs, optimize resource distribution and prevent future crises in the healthcare sector (Kumar et al., 2021). Pharmacies and hospital supply chains, which rely on precise inventory management and timely deliveries, particularly benefit from these innovations, as they help minimize stockouts and overstocking, ensuring the continuous availability of essential medicines and medical equipment.

This thesis analyzes risk management and resilience in the healthcare supply chain to identify effective strategies for strengthening its robustness. Through a systematic literature review, it explores key challenges in the sector and assesses solutions proposed by academia and industry. By synthesizing best practices and emerging technologies, this work provides practical insights for policymakers and

professionals, contributing to the development of more resilient and sustainable models for healthcare resource management.

The structure of the present dissertation is organized into three principal chapters. The initial chapter introduces the concept of supply chain management, analyzing its main trends and emphasizing its key role in modern industries. Subsequently, it examines the healthcare supply chain, highlighting its benefits, critical issues and current challenges. Additionally, the chapter explores the concept of risk management and resilience within the healthcare supply chain, focusing on the main obstacles that hinder its effective implementation (Christopher & Peck, 2004).

Chapter 2 is dedicated to the literature review and describes in detail the methodology adopted for the analysis. This section illustrates the phases of the research process, starting with the definition of inclusion criteria and the formulation of research questions related to the use of digital technologies to strengthen healthcare supply chain resilience, reduce vulnerabilities and optimize product distribution processes. The search queries used to identify the most relevant studies are then presented, followed by the selection process of the articles, based on the analysis of abstracts, the availability of full texts and the critical evaluation of study contents. The second part of the chapter focuses on classifying the analyzed studies and discussing the obtained results, with particular attention to the challenges addressed and the strategies proposed in the scientific literature. (Pettit, Fiksel, & Croxton, 2010).

The final Chapter provides a conclusion to the study and discusses the future perspectives. The section provides a concise overview of the study's primary benefits, emphasizing their practical relevance for enhancing supply chain resilience and risk management. A critical analysis of the study’s limitations is also provided, with particular attention to factors that may influence the applicability of the identified strategies. Lastly, the chapter suggests future research directions, proposing areas of study and potential developments in the integration of advanced technologies for optimizing the healthcare supply chain.

1 THEORETICAL BASICS

This chapter provides an overview of supply chain management, its relevance in modern industries and its impact on the healthcare sector. Given the critical nature of healthcare services, effective supply chain management is essential to ensuring the timely delivery of medical supplies, equipment and pharmaceuticals, directly influencing patient care and operational efficiency. Additionally, the concepts of risk management and resilience in the healthcare supply chain are explored, as disruptions—whether caused by global crises, demand fluctuations or logistical challenges—can severely affect healthcare delivery. In this context, resilience becomes a key objective, with supply chain strategies aimed at enhancing adaptability and minimizing vulnerabilities.

1.1 INTRODUCTION TO THE SUPPLY CHAIN

The supply chain is a complex system that integrates all the stages through which a product or service is created, distributed and delivered to the final consumer (figure 1). In recent years, particularly in the post-pandemic era, the importance of digitalization in supply chain management has increased significantly. The COVID-19 crisis exposed vulnerabilities in global supply networks, causing disruptions that highlighted the need for greater agility, resilience and transparency. Companies faced unprecedented challenges, such as sudden demand shifts, supplier shortages and logistical bottlenecks, which accelerated the adoption of digital solutions to enhance real-time visibility and improve decision-making. In this context, the digitization of the supply chain is now essential for optimizing these flows, improving visibility and traceability and reducing operational costs, an aspect that is becoming increasingly critical for modern businesses [1].

FIGURE 1: SUPPLY CHAIN JOURNEY, FROM RAW MATERIALS TO THE FINAL CONSUMER, SOURCE [2]

The structure of a supply chain varies based on a company's business model. These components are usually:

- Customers: in the context of a supply chain, customers represent a fundamental focal point. They initiate the processes by placing an order with the retailer. The subsequent fulfilment of these orders is the responsibility of the retailer, who can either source products from existing inventory or place a new order with a wholesaler or manufacturer. In some cases, customers bypass these components and contact manufacturers directly.
- Retailers/Distributors: retailers act as intermediaries between customers and manufacturers. The primary function of retailers is to stock products in their stores in order to meet customer needs. As part of this process, retailers place orders with manufacturers to replenish their inventory. Typically, purchase orders originate from retailers; however, in instances where an arrangement exists to share point-of-sale (POS) data with manufacturers, the responsibility for monitoring inventory levels and automatically replenishing them can be transferred to the manufacturer.

- Manufacturers: it is imperative to acknowledge the pivotal role manufacturers play in shaping the intricate structure of supply chains. In accordance with prevailing market conditions, manufacturers may adopt either a pull strategy or a push strategy in their attempts to generate demand for the movement of products within the supply chain. Subsequent to this, they then proceed to plan their production schedules in accordance with the resulting demand.
- Suppliers: the role of suppliers in the manufacturing process is to ensure a continuous supply of raw materials. Manufacturers, for their part, place orders with suppliers in accordance with the forecasts of demand that have been prepared for them. Demand forecasting is a complex process and manufacturers therefore endeavor to integrate their processes with those of suppliers, thus enabling a more effective response to fluctuations in demand [3].

Additionally, the supply chain cycle is made up of several crucial stages that allow the smooth flow of goods and services. The first stage, product development, is where ideas are transformed into tangible products. This phase includes Research and Development (R&D) to innovate and conceptualize new products, design to make the product manufacturable, prototyping to test and refine the product before mass production. It is essential to emphasize that aligning product development with customer needs and market demands, ensuring that the design is cost-effective and scalable for production.

Next, the raw materials sourcing phase is crucial, where suppliers are selected based on criteria such as cost, quality and reliability. This phase also involves negotiating purchase contracts and logistics to transport raw materials to manufacturing sites. Building strong relationships with suppliers is important for improving reliability, quality, sustainability and ethical sourcing practices should also be considered.

The following phase is manufacturing where production planning takes place, products are assembled on production lines and quality control is employed to ensure that the products fulfill the requisite standards. It is imperative to optimize production processes for efficiency and to minimize defects and returns.

Once production is completed, the process moves to distribution, which involves managing the logistics of getting finished products to market. This phase includes warehousing to store goods, managing inventory to match supply and demand, and transporting goods to retailers or directly to consumers. The key to minimizing shipping costs and avoiding both overstocking and out-of-stocking is to select strategic warehouse locations and implement effective inventory management systems.

Then, to create demand and sell the finished products, sales and marketing are essential. This stage involves marketing to promote the product, developing sales strategies and acquiring new customers.

Finally, the customer service phase marks the concluding stage of the supply chain, emphasizing the enhancement of customer satisfaction and the cultivation of loyalty. This phase involves post-purchase support, handling returns and gathering feedback to enhance future products and services. Delivering outstanding customer service fosters trust and promotes repeat business, while effective returns management ensures customer satisfaction and reduces costs.

These stages together create a continuous flow that allows the product to move efficiently from suppliers to consumers, meeting market demands in a timely and cost-effective manner [4].

However, supply chains face critical challenges that can reduce efficiency and responsiveness, such as:

- Long lead times: extended lead times can create inflexibility, reducing a supply chain's ability to respond quickly to market changes. Structural issues, such as lengthy planning frozen periods and large minimum order quantities (MOQs), can further impede flow and elongate delivery times.
- Inefficient processes: poorly optimized processes can lead to waste, increased costs and delays, reducing overall performance.
- Lack of visibility: without real-time tracking and data integration, companies may struggle to monitor inventory levels, shipments and potential disruptions, leading to inefficiencies.

- Supplier reliability issues: dependence on unreliable suppliers can lead to unexpected shortages or quality issues that disrupt the supply chain.
- Inadequate risk management: failure to identify and mitigate potential risks, such as geopolitical tensions or natural disasters, can leave supply chains vulnerable to significant disruptions [5].

Regarding this last point, effective risk management in the supply chain is vital to ensure the smooth and efficient movement of goods and services from suppliers to customers. In today's complex business landscape, supply chains encounter various risks that can disrupt operations, raise costs, and harm reputations. Organizations must proactively identify, assess, and mitigate risks to protect their supply chain performance, ranging from natural disasters and geopolitical uncertainties to supplier failures and cyber threats. Companies adopt strategies such as supplier diversification and the integration of advanced technologies to mitigate these risks [6].

In addition, the future of supply chains is shaped by the following trends:

- Artificial Intelligence (AI) and Machine Learning: improving demand forecasting and inventory management.
- IoT and real-time tracking: enhancing supply chain visibility.
- Blockchain technology: improving security and transparency in transactions.
- Sustainability and green supply chains: reducing carbon footprints and adopting circular economy practices.
- Automation and robotics: improving warehouse operations and last-mile deliveries.
- Cloud-based solutions: enabling flexibility and seamless data integration.
- 5G connectivity: accelerating real-time logistics operations.
- Augmented Reality (AR) in warehousing: streamlining inventory management and training.

- Cybersecurity measures: protecting digital networks from threats.
- Data-driven decision-making: optimizing operations through analytics [7].

Given these developments, supply chain management (SCM) (figure 2) remains pivotal for companies looking to optimize operations. SCM involves centralized management and optimization of the flow of goods, information and resources across the entire supply chain, from the procurement of raw materials to the final delivery of products to customers. The process requires precise coordination of each stage—planning, sourcing, production, delivery and returns—to ensure timely product delivery while minimizing waste and inefficiencies. By effectively managing their supply chains, companies can cut excess costs, streamline their operations and achieve a competitive advantage in the marketplace. Furthermore, efficient SCM helps prevent costly product recalls and lawsuits. enhances. product quality and boosts customer satisfaction. This holistic approach is essential for businesses to adapt to the dynamic market environment and meet customer demands effectively [8].

FIGURE 2: THE MAIN AREAS MANAGED BY SUPPLY CHAIN MANAGEMENT (SCM), SOURCE [9]

To achieve these goals, companies adopt different supply chain models, each tailored to specific operational needs and market conditions. The traditional model follows a linear process where suppliers provide raw materials, which are then transformed into goods through production. Afterward, the products are distributed to retailers or directly to end consumers. This approach mainly focuses on operational efficiency, but it can be rigid in dynamic market contexts.

With the advancement of technology, the digital supply chain model has also emerged. This approach integrates advanced technologies such as Artificial Intelligence (AI), blockchain and the Internet of Things (IoT) to improve visibility, optimize flows and support real-time decision-making. Companies adopting this model can gain greater transparency in their operations and respond quickly to any issues that may arise [10]. Another widely used model is the Just-in-Time (JIT) model, which focuses on minimizing inventory. This system synchronizes procurement with production, reducing warehouse costs and optimizing the use of resources [11]. Similarly, the Lean model focuses on eliminating waste and optimizing every stage of the process, improving overall efficiency [12]. In contrast, the Agile model is known for its ability to quickly adapt to unexpected market changes, allowing a rapid response to fluctuations in demand and changes in operational conditions [13].

Furthermore, companies can enhance operational efficiency through structured business strategies. Key initiatives include optimizing information and product flow by eliminating non-value-added activities, improving supply chain segmentation to address diverse market needs and increasing agility to respond swiftly to market changes. Effective inventory management also plays a vital role in reducing capital immobilization and improving working capital. To support these improvements, companies rely on key analytical tools such as demand analysis (ABC/XYZ), warehouse optimization, lead-time production evaluation (EPE), supplier assessment through Kraljic's Matrix and supply chain lead-time mapping. These methodologies help identify inefficiencies, enhance responsiveness and optimize resource utilization, ultimately leading to increased productivity and cost savings [5].

Beyond choosing a suitable supply chain model, advanced technologies play a key role in enhancing supply chain efficiency. In today's rapidly changing global landscape, characterized by uncertainty, advanced supply chain technologies have become essential**.** Artificial intelligence, along with data analytics, is revolutionizing the industry by enhancing demand forecasting and inventory management [14]. Cloud-based platforms help companies maintain constant

control over their operations, fostering integration between different players within the supply chain [15].

However, beyond technology, businesses must also choose the right operational approach to manage supply and demand effectively.

The push supply chain model operates on the principle of projected demand, where companies use long-term forecasts to determine what products to produce and when to deliver them. The main advantages of this model include predictability, as companies have a clear idea of what they will receive and when, allowing them to plan their production and storage accordingly. Additionally, retailers can prepare storage space in advance for the incoming stock.

On the other hand, the pull supply chain model relies on actual customer demand. Only orders can initiate the production of an item. The key benefits of this model include reduced inventory costs, as companies avoid the expenses associated with holding unsold excess inventory, and increased adaptability, making it ideal for businesses with a low product mix, high demand uncertainty, and minimal reliance on economies of scale. However, there is a risk that if the company is unable to ramp up production quickly, it may not have enough stock to satisfy the demand.

The hybrid supply chain model integrates both push and pull strategies. For example, a company might stockpile raw materials in advance (push strategy) but only assemble the final product after receiving an order (pull strategy). This model is generally recommended for products that offer significant cost advantages due to scale and face considerable fluctuations in demand.The main advantages of this model are efficiency, as it minimizes inventory holding costs and delivery lead time and flexibility, as it balances the benefits of both push and pull models [16].

Sustainability is increasingly central to the future of supply chain management. Many companies are incorporating eco-friendly practices, such as using sustainable materials, optimizing transport routes to reduce emissions and improving transparency in production processes [17]. Not only does this meet

increasing consumer demands for environmental responsibility, but it also helps companies comply with evolving regulations within their industries.

Ultimately, adopting a strategic method for managing the supply chain is no longer just a competitive edge, it is a necessity for navigating the complexities of the global marketplace. By embracing new technologies, prioritizing sustainability and increasing responsiveness to market dynamics, businesses can ensure their success in the years to come.

1.2 OVERVIEW OF SUPPLY CHAIN IN THE HEALTHCARE INDUSTRY

The healthcare supply chain (figure 3) is a complex and multifaceted network of processes and interconnected actors, all working together to guarantee the availability of essential products and services required for patient care. This network spans various resources, including pharmaceuticals, medical devices, hospital equipment and healthcare materials, which are carefully managed through logistical, administrative and organizational activities. Well-managed supply chain operations are vital for maintaining the continuity of healthcare services, meeting fluctuating demand and guaranteeing that patients receive the necessary care in a timely manner.

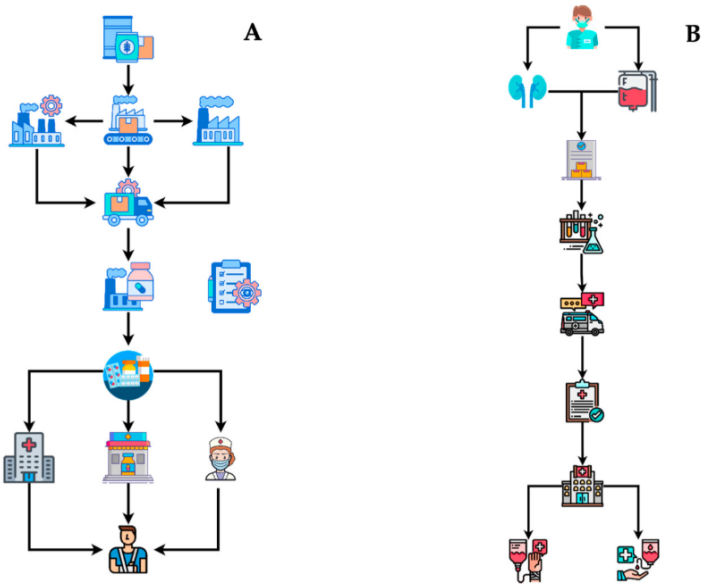

FIGURE 3: STAGES OF THE HEALTHCARE SUPPLY CHAIN, IN PARTICULAR FOR DMDS (A) AND BOTS (B), SOURCE (FIORE ET AL., 2023)

An essential aspect of managing the supply chain in healthcare is the harmonization among the various actors involved, like vendors, distributors and healthcare institutions, to ensure that necessary resources are always available. This coordination is crucial as the healthcare sector operates in a highly regulated environment, where every phase of the chain must meet strict quality and safety standards. For instance, the transportation of sensitive medical devices or pharmaceuticals must comply with specific protocols to guarantee their optimal transport, preventing damage and ensuring their integrity. Smooth communication and constant collaboration among the actors involved help avoid misalignments and ensure that resources arrive on time, thus contributing to the successful delivery of care and the continuity of healthcare operations [18]

Logistics is another integral component in the healthcare supply chain. Efficient logistics not only guarantee that medical supplies are delivered to the right place at the right time, but they also ensure that the products arrive in optimal conditions for patient use. Many healthcare products require specific storage and handling conditions. For example, certain vaccines and medications are highly sensitive to temperature fluctuations, meaning their timely and accurate delivery is vital to maintaining their efficacy. This aspect of the supply chain requires a thorough understanding of logistics management, as delays or disruptions in product delivery can cause significant operational challenges for healthcare facilities, potentially leading to the postponement of critical treatments [19].

Additionally, managing procurement practices effectively is key to maintaining balance in the supply chain. Hospitals and healthcare institutions must implement intelligent purchasing strategies that ensure access to critical supplies while preventing waste. This requires a careful approach to inventory management, where forecasting demand and maintaining optimal stock levels are essential. Procurement strategies should consider not just cost savings, but also the quality and reliability of suppliers. Building long-term, stable relationships with trusted suppliers helps healthcare organizations to mitigate the risk of product shortages or delays that could disrupt care delivery [18].

Equally important is the necessity for standardization throughout the supply chain. In a globalized healthcare market, organizations must manage various

standards effectively and quality requirements for medical products. Globally recognized standards, such as those set by the World Health Organization (WHO) or regional organizations like the European Medicines Agency (EMA) and the U.S. Food and Drug Administration (FDA), guarantee the safety and effectiveness of the products in use. However, differences in regulatory environments across different countries and regions can present challenges for supply chain management. For example, a medical device approved in one country might need additional certification or modifications to fulfill the requisites of another, leading to delays in the delivery of products. Navigating these varying regulations while ensuring compliance across all markets is a significant challenge for healthcare organizations, requiring careful planning and constant updates to regulatory knowledge (Whitman et al., 2024).

The sustainability aspect of the healthcare supply chain is also becoming increasingly important. As the global focus on environmental responsibility grows, healthcare organizations are striving to reduce their carbon footprint and minimize their environmental impact. This includes adopting more sustainable practices in areas such as packaging, waste management and transportation. For instance, the use of recyclable or biodegradable packaging materials is a growing trend within industry, helping to reduce the waste generated by healthcare products. Additionally, optimizing transportation routes and reducing fuel consumption by consolidating shipments can lead to significant reductions in greenhouse gas emissions. These sustainability initiatives are important not only for environmental reasons but also for reducing costs in the long term, as energy-efficient practices often result in cost savings (Nakrem, 2024).

Moreover, stakeholder collaboration extends beyond healthcare providers and suppliers to include public and private health institutions, as well as governmental and non-governmental organizations. Through joint initiatives, these stakeholders can develop comprehensive strategies that ensure the consistent availability of critical medical supplies. Public-private partnerships, for example, are becoming increasingly common in the healthcare sector, where governments work with healthcare providers and manufacturers to ensure a steady and secure supply of essential healthcare resources. In times of crisis, such partnerships

prove invaluable in facilitating the rapid distribution of critical supplies to areas most in need (OECD, 2024).

Finally, healthcare supply chains must adapt to the ever-evolving needs of the patient population. As new medical conditions and emerging diseases continue to shape healthcare priorities, the ability to swiftly respond to changing demands is crucial. This involves monitoring shifts in healthcare trends and adjusting supply chain strategies accordingly. For example, the rapid expansion of telemedicine and home healthcare services has created emerging need for particular medical products, such as home diagnostic tools and personal protective equipment. Ensuring the supply chain is flexible enough to accommodate these shifts and support the broader transformation of healthcare delivery models is essential for maintaining the effectiveness and efficiency of healthcare services in the long term [20].

In comparison with manufacturing supply chains, the supply chain in healthcare is different due to its complexity and the critical nature of the products involved. While both sectors require timely and efficient delivery of goods, the healthcare sector is uniquely focused on life-saving products and services, which must be handled with a higher degree of care and meet more stringent regulatory standards. Unlike manufacturing, where supply chain disruptions can often be mitigated with alternate sourcing or adjustments in production, disruptions in healthcare can result in direct harm to patients, making reliability and strict compliance paramount. Moreover, the healthcare supply chain must also adapt to evolving patient needs, regulatory changes and the sensitivity of medical products, such as temperature-sensitive pharmaceuticals.

The global events in recent years, such as the global supply chain disruptions due to raw material shortages, regional conflicts and geopolitical tensions, have had significant impacts on healthcare logistics. These events have exacerbated existing challenges like the transportation of medical supplies, delays in the manufacturing of critical products and an increased demand for certain healthcare goods. For example, the war in Ukraine disrupted both the production of basic materials and transport corridors, affecting the distribution of medical supplies in certain regions. Similarly, shortages in raw materials, such as

semiconductors, have affected the production of essential medical devices. These global challenges have highlighted the vulnerabilities within the production chain of healthcare, emphasizing the importance of resilience, flexible logistics strategies and strategic stockpiling to ensure the uninterrupted delivery of essential healthcare services, especially in crisis situations.

Effective healthcare supply chain management is not only about managing products but also about managing relationships, processes and compliance. The ability to maintain a stable and responsive supply chain relies on continuous collaboration among stakeholders, adherence to evolving regulatory frameworks and proactive adaptation to market and patient needs. By integrating efficient procurement strategies, maintaining high operational standards and fostering strong partnerships across the sector, healthcare organizations can ensure the consistent, reliable and safe delivery of healthcare services [21].

1.3 THE CONCEPT OF MANAGING RISKS IN THE HEALTHCARE SUPPLY CHAIN

Managing risk in the healthcare supply chain is not just a strategic concept, but a critical necessity to ensure the continuity of healthcare services and, above all, patient safety. The healthcare supply chain is complex, multidimensional and globally interconnected, which significantly increases the risk of disruptions. Every element of the supply chain, whether it is pharmaceuticals, medical devices or healthcare equipment, plays a vital role in patient care and even a small disruption can have devastating consequences.

The main challenges in risk management in this sector include uncertainty in demand, geopolitical risks, natural disasters and the increasing regulatory complexity. Demand uncertainty, for example, is amplified by the unpredictable nature of global health crises like pandemics, which can drastically change the volume of requests for specific drugs or medical devices. The recent COVID-19 pandemic highlighted the vulnerability of healthcare supply chains, revealing how a disruption in supplies can have devastating effects on patient treatment and hospitals' ability to respond quickly to emergencies.

Another major risk is supplier dependency on specific markets or producers. Due to globalization, many healthcare organizations depend on a network of suppliers spread across various geographic regions, some of which are more susceptible to external factors like conflicts, natural disasters or political crises. This implies a constant need to monitor and assess the resilience of their suppliers. The supply shortages during the pandemic pushed many companies to reconsider and diversify their procurement strategies to reduce reliance on single sources. For example, Medtronic diversified its suppliers for critical components of medical devices, such as ventilators, by relocating production to multiple countries, reducing the risk of disruptions caused by regional crises.

Regulatory compliance is another major barrier in risk management. The healthcare sector is highly regulated, with laws and regulations varying from country to country. Companies must ensure that their suppliers meet strict quality and safety standards to avoid legal sanctions and reputational damage. For example, medical devices must adhere to specific regulations, such as those set by the FDA in the United States or the EMA in Europe. Maintaining strict control over these requirements requires continuous monitoring of regulations and a strong ability to adapt to changes in real-time [22].

A key strategy for mitigating these risks is leveraging advanced technologies. Solutions based on artificial intelligence (AI) and big data analysis are key tools that allow healthcare organizations to obtain real-time visibility into their supply chain. For instance, blockchain is being increasingly applied to enhance product traceability throughout the entire supply chain, ensuring that each step—from production to distribution—is secure and transparently documented. These technological tools not only reduce the risks associated with product counterfeiting but also assist in preventing and managing supply chain disruptions through prompt actions. For instance, GSK uses AI-driven forecasting models to anticipate demand fluctuations and optimize stock levels, reducing the risk of shortages during crises.

Another key technology is the Internet of Things (IoT), which enables monitoring and tracking the conditions of products in real-time, including temperature-sensitive drugs and devices. For example, a drug that needs to be kept at specific

temperatures during transportation can be monitored through IoT sensors, which send alerts in case of deviations. This level of control helps prevent damage and ensures that products arrive in optimal condition for use (Foropon, 2024). Pfizer, for example, implemented IoT-based temperature monitoring for its COVID-19 vaccine distribution, ensuring that doses remained within required temperature ranges throughout the supply chain.

Along with technological solutions, one of the most effectual risk mitigation strategies is supplier diversification. During the pandemic, many hospitals and healthcare organizations faced shortages of protective devices, such as masks and gloves, due to the concentration of production in a few regions of the world. Diversifying suppliers geographically, as well as seeking alternative suppliers and building closer relationships with local producers, were fundamental steps to avoid similar disruptions in the future (Dogbe et al.,2023). For instance, 3M expanded its N95 mask production capacity by establishing additional manufacturing sites in different regions, reducing dependency on any single supply source. Stock planning is another crucial aspect that helps maintain sufficient stock levels, even during periods of high demand (Čerkauskienė & Meidutė-Kavaliauskienė, 2023) .

Collaboration among stakeholders is another pillar of risk management. Communication between hospitals, suppliers, distributors and governments is essential to ensure a coordinated response to any crisis. The pandemic showed that only through a solid communication network and the timely sharing of information could the emerging challenges be effectively addressed. For example, shared information about demand and supply trends enabled a more equitable distribution of healthcare resources, preventing waste and optimizing stock management.

An additional factor that must not be ignored is the significance of ongoing training for healthcare supply chain professionals. Risk management is not just about technologies and emergency plans, but also about skills. The healthcare sector must prioritize investing in training its teams to ensure they are equipped to handle crisis situations, proficient in utilizing new technologies, and fully

understand the significance of risk management as a core element of healthcare quality [23].

Effective risk management not only prevents disruptions but ensures that patients and healthcare providers always have access to the resources they need.

1.4 THE CONCEPT OF RESILIENCE IN THE HEALTHCARE SUPPLY CHAIN

Resilience in the healthcare supply chain denotes a system's capacity to anticipate, prepare for, react to and recover from disruptions, ensuring that essential services, products and resources remain available during times of crisis. In the last ten years, particularly in the course of the COVID-19 pandemic, the vulnerabilities of healthcare supply chains were starkly revealed, underlining the importance of building robust systems capable of not only managing regular operations but also adapting to unexpected shocks. Resilience in this context does not merely mean returning to a prior state after a disruption but involves continuous learning, adaptation and strengthening capabilities to tackle future challenges more efficiently (Zamiela et al., 2022).

Flexibility is a core element of resilience in healthcare supply chains. While efficiency in operations and cost reduction has traditionally been the primary focus of supply chain management, resilience introduces a shift toward balancing efficiency with flexibility. For example, having the ability to quickly adapt supply routes, change suppliers or shift manufacturing priorities in response to unforeseen circumstances has become paramount. This flexibility is also necessary to navigate challenges arising from global events, such as pandemics or political instabilities, which can disrupt the supply of essential medical supplies. Healthcare providers must be prepared to adapt in real time, maintaining critical inventory levels and ensuring continued access to essential medicines and equipment even during periods of heightened demand (Alemsan et al., 2022). One notable example of flexibility in healthcare supply chains is Roche, a pharmaceutical company that leveraged digital supply chain solutions and AI-driven forecasting tools to enhance its response capabilities during the pandemic. By integrating real-time data analytics, Roche improved demand visibility,

enabling faster distribution of critical medications and diagnostics across multiple regions [24].

An important element in ensuring resilience is the diversification of supply sources. Excessive dependence on a single source or region for essential medical supplies, such as personal protective equipment (PPE), ventilators or pharmaceuticals, exposes healthcare systems to significant risks. Disruptions in one region, such as natural disasters, political unrest or pandemics, can create widespread shortages. By diversifying supply chains, organizations can mitigate these risks. However, diversification also requires a careful balancing act between risk, cost and operational complexity, which can prove challenging, especially for healthcare organizations with limited resources. The ability to draw from a wider range of suppliers and sources allows for the more efficient reallocation of resources during periods of scarcity, ensuring that care providers can continue their operations (Alemsan & Tortorella, 2022). A practical example of supply chain diversification is the creation of the European Union's Health Emergency Preparedness and Response Authority (HERA), established in 2021. HERA evaluates potential health threats, promotes research, ensures the availability of critical manufacturing and contributes to stockpiling essential medical products. During health crises, HERA activates emergency funding and helps coordinate the monitoring, procurement and acquisition of medical supplies, thereby strengthening the resilience of Europe's healthcare supply chain [25].

Another key to building resilience is the incorporation of advanced technologies, which can greatly improve, which can significantly enhance supply chain performance and flexibility. Technologies such as artificial intelligence (AI), machine learning (ML) and predictive analytics have revolutionized healthcare supply chains by providing tools to forecast demand more accurately, predict potential disruptions and optimize inventory management. AI, in particular, has the ability to process vast amounts of data in real-time, identifying trends and patterns that may not be immediately apparent to human operators. These technologies enable the system to better anticipate surges in demand, respond to supply shortages and automate various supply chain processes, reducing the human error factor and increasing the speed and accuracy of decisions made

during times of crisis (Ugwu et al., 2024). Furthermore, Blockchain technology can improve the traceability and transparency of supply chains, enabling better monitoring and more dependable tracking of medical goods as they move through various stages of the supply network (Fiore et al., 2023). For instance, Pfizer implemented blockchain technology to enhance the traceability of COVID-19 vaccine distribution. By using a secure and transparent ledger, Pfizer improved the monitoring of shipments, reduced counterfeit risks and ensured the integrity of temperature-sensitive vaccines throughout the supply chain. [26].

In addition to technological advancements, fostering collaboration among various stakeholders is essential to strengthening supply chain resilience. Collaboration between healthcare providers, governments, suppliers and logistics companies enables more effective coordination of resources and a faster response to emergencies. For example, shared platforms where real-time information can be accessed by all involved parties can allow for better allocation of scarce resources and faster decision-making during critical situations. These collaborative models also provide a foundation for strategic partnerships, where healthcare institutions can work closely with suppliers to make sure that incidental plans are in place and supply chain risks are minimized. A well-coordinated response involving all key players can reduce the negative impact of disruptions on the healthcare system and ensure that patient care is not compromised (Tuyishime et al., 2025). An important example of collaboration is the GAVI Alliance, a global partnership between public and private entities aimed at ensuring worldwide immunization access. GAVI has played a crucial role in increasing vaccine availability in low-income countries, improving resilience in global healthcare supply chains [27].

Despite its benefits, building resilience presents ajor obstacles to creating a resilient healthcare supply chain. The primary challenge in this regard is cost. Building resilience often requires significant investment in infrastructure, technology and strategic partnerships. Governments, private healthcare organizations and international bodies must prioritize long-term investment in resilient systems, recognizing that the cost of inaction can be far higher in the event of major disruption. Furthermore, such investments are often complex and require cross-border cooperation, especially in global supply chains where

regulatory and logistical differences can complicate the creation of a seamless, resilient network [28].

Uncertainty also presents a major obstacle to creating resilient healthcare supply chains. Disruptions are often unpredictable, making it difficult to prepare for every potential scenario. While forecasting tools and technologies such as AI can improve decision-making, they cannot fully eliminate the uncertainties inherent in global supply chains. The volatility of certain products, such as medications or vaccines, due to fluctuations in demand, seasonal trends or geopolitical factors, adds another layer of complexity. In these circumstances, healthcare systems must be able to quickly adapt and realign resources to maintain stability and meet public health needs [29].

Another challenge is the trade-off between resilience and sustainability. While the healthcare sector increasingly focuses on sustainable practices to reduce its environmental impact, these efforts must be balanced with the need for resilience. For instance, supply chains that rely on local, sustainable sources of medical products may be more vulnerable to disruption during times of crisis, as these suppliers might not have the capacity or infrastructure to scale up quickly. Conversely, global sourcing may increase efficiency but also elevate risks related to long supply lines and dependency on international transportation networks, making it harder to maintain sustainability goals. Finding the right balance between these two priorities—resilience and sustainability—is one of the most pressing challenges facing healthcare organizations today [30].

Finally, culture and leadership pose a significant challenge. Effective supply chain resilience requires a shift in organizational culture, where healthcare providers and leaders adopt a proactive, rather than reactive, approach to risk management. This shift involves fostering a mindset of continuous improvement and Committing resources to training and development to guarantee that teams are ready to tackle disruptions. Additionally, leadership must prioritize resilience as a core value, ensuring that it is embedded in strategic planning and decision-making processes across the organization [28].

2 LITERATURE REVIEW

This literature review aims to shed light on the main challenges, solutions, advancements and theories related to risk management and resilience in the healthcare sector. The chapter begins with an overview of the methodology adopted for the selection and analysis of studies. Subsequently, the classification criteria used to categorize the analyzed articles are outlined. Finally, each selected article is summarized, highlighting the key elements that justified its inclusion in this study.

2.1 MATERIAL AND METHODOLOGY

A solid and well-defined methodology is essential to ensure the validity and reliability of any academic research. In this study, methodology is structured in several phases, from defining the inclusion criteria to selecting and analyzing the articles, followed by the construction of a data corpus for subsequent interpretation.

The first phase involved defining the inclusion criteria, establishing that the selected articles should be published in English and fall within the time range of 2010-2024. Subsequently, the research questions - “What are the main logistic, procurement and risk management challenges in the global healthcare supply chain during crises such as the COVID-19 pandemic?” and “How can the integration of digital technologies, such as IoT and artificial intelligence, improve resilience and risk management in the healthcare supply chain, while also reducing vulnerabilities and delays in product distribution?”- were formulated, from which keywords were derived and used to build the search queries within the Scopus database:

- ("healthcare" AND "supply chain" AND "cris*")
- ("healthcare" AND "supply chain" AND "digital technolog*" AND "resilience")
- ("healthcare" AND "supply chain" AND "digital technolog*" AND "risk")
- ("healthcare" AND "logistic/logistics" AND "digital technolog*" AND "risk")
- ("healthcare" AND "supply chain" AND "IoT" AND "resilience")
- ("healthcare" AND "supply chain" AND "IoT" AND "risk")
- ("healthcare" AND "logistic" AND "IoT" AND "risk")

- ("healthcare" AND "supply chain" AND "Blockchain" AND "resilience")
- ("healthcare" AND "supply chain" AND "Blockchain" AND "risk")

Scopus is a prominent database for peer-reviewed scientific literature, widely utilized for conducting systematic reviews, thanks to its comprehensive coverage across various disciplines and its sophisticated bibliometric analysis tools (Schotten et al., 2017). This database provides detailed information for each indexed article, such as the year of publication, document type (e.g., scientific article), authors, the university affiliation of each author with the corresponding country, abstract, keywords supplied by the authors and the citation count the article has accumulated. After obtaining the search results, a selection was made to verify the relevance of the articles to the research questions. This process took place in several stages: initially based on the analysis of the title and abstract, followed by the accessibility of the full text, followed by a comprehensive examination of the entire text. The selected articles were organized into a structured corpus (Appendix) within a table, which collects both general information (e.g., authors, year of publication, methodology adopted, type of study) and specific data related to the research questions. The idea of a corpus within the context of academic research, refers to a systematically collected set of textual documents intended for qualitative or quantitative analysis (Reynaud & Todescat, 2017).

Using the information gathered from the corpus, the results were analyzed and will be addressed in the final paragraph of this chapter.

2.2 PAPER CLASSIFICATION

From the analysis of the literature, two main classes of study closely related to the topic have emerged. These categories stand out for their specific focus and represent the key areas of research. Specifically, the following have been identified:

LOGISTICS, PROCUREMENT AND RISK MANAGEMENT CHALLENGES IN HEALTHCARE SUPPLY CHAINS DURING CRISES

Crises can have a significant impact on healthcare supply chains, complicating logistics, procurement and risk management. A striking example is the COVID-19 pandemic, which caused severe shortages of medicines, essential medical devices and life-saving equipment, putting the entire healthcare system under extreme pressure. In addition to the difficulty of sourcing critical materials, the crisis highlighted challenges in inventory management, fair resource distribution and the ability to rapidly adapt to ever-changing demand. Furthermore, transport restrictions, border closures and production disruptions further exacerbated logistical challenges, emphasizing the need for more resilient and flexible strategies to tackle future emergencies.

DIGITAL TECHNOLOGIES FOR RESILIENCE AND RISK MANAGEMENT IN HEALTHCARE SUPPLY CHAINS

Resilience and risk management are two crucial aspects of the supply chain, particularly in healthcare, where inefficiencies in these areas can have serious consequences, such as the shortage or delay in the delivery of essential medicines and medical equipment, putting patients' lives at risk. A striking example was the COVID-19 pandemic, which emphasized the weaknesses in the healthcare supply system, pushing stakeholders in the sector to strengthen risk management and resilience strategies to prevent future crises. In recent times, technological progress has introduced innovative solutions to tackle these issues. Digital technologies such as the Internet of Things (IoT), Blockchain and Artificial Intelligence (AI) are becoming increasingly central to managing healthcare supply chains. These tools help improve product traceability, enhance inventory control, improve demand forecasting precision and track ongoing processes in real time. Additionally, the adoption of digital solutions enables better safeguarding of

sensitive data, like patient details, by minimizing the risk of breaches and enhancing the overall security of the system.

2.3 LOGISTICS, PROCUREMENT AND RISK MANAGMEENT CHALLENGES IN HEALTH

In this paragraph, the articles clustered within this class will be summarized one by one, with a focus on the distinctive features of each paper related to the theme of resilience and risk management in healthcare supply chains during crises. The emphasis will be placed on the specific difficult tasks faced by the healthcare sector, such as logistical disruptions, procurement delays and risk mitigation strategies. Furthermore, the articles will highlight the key insights on the ways in which these challenges were tackled during pivotal events like the COVID-19 pandemic and the lessons learned for strengthening future resilience in healthcare supply chains.

2.3.1 Supply Chains Problem During Crises: A Data-Driven Approach (Salamian *et al.*, 2024)

The document addresses the challenges of hospital evacuations and pharmaceutical supply chains during emergencies, proposing a bi-objective optimization framework. This approach combines Mixed-Integer Linear Programming (MILP) with machine learning, particularly a Gated Recurrent Unit (GRU) neural network, for precise drug demand forecasting and dynamic resource allocation. It focuses on minimizing costs and maximizing patient satisfaction while ensuring robust supply chain reliability by accounting for probabilistic demand patterns and disruption risks. Additionally, the Grasshopper Optimization Algorithm (GOA) and the E-constraint method are employed to efficiently address the multi-objective nature of the problem.

2.3.2 Evaluation of COVID-19 mortality using machine learning regression methods based on health system indicators (Bulut *et al.*, 2024)

The document evaluates the performance of healthcare systems throughout the COVID-19 pandemic, utilizing machine learning regression techniques. By analyzing healthcare system indicators grouped into three dimensions—accessibility, financing and workforce—the study predicts COVID-19 death rates across 27 OECD countries from 2006 to 2019. Three methods, Random Forest Regression, Neural Network Regression and Gaussian Process Regression (GPR) were applied, with GPR showing the best predictive performance (figure

4). The findings emphasize the role of machine learning in uncovering relationships between healthcare indicators and mortality, aiding resource allocation and patient care. Recommendations include prioritizing community healthcare, advanced technologies, leadership, global governance and flexible supply chains for protective equipment.

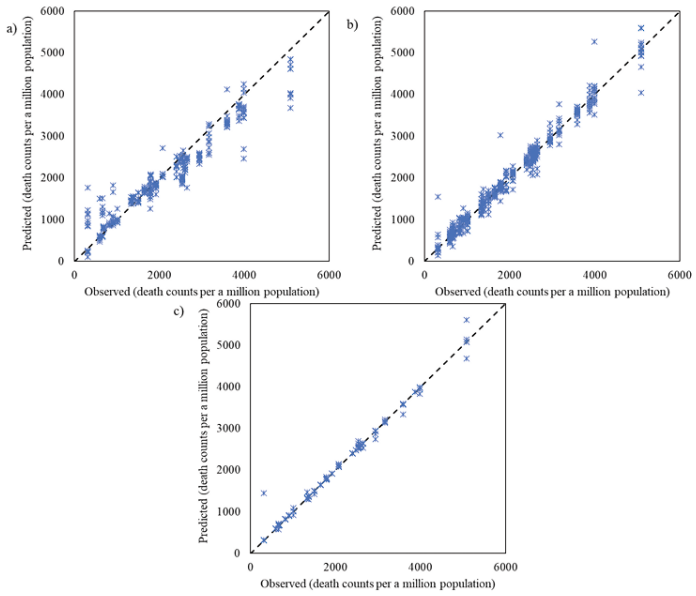

FIGURE 4: THE OBSERVED AND PREDICTED COVID-19 MORTALITY BASED ON A) RANDOM FOREST REGRESSION, B) NEURAL NETWORK REGRESSION AND C) GAUSSIAN PROCESS REGRESSION, SOURCE (BULUT ET AL., 2024)

2.3.3 Impact of COVID-19 on the neglected tropical diseases: a scoping review (Butala *et al*., 2024)

The document investigates how the COVID-19 pandemic disrupted the management and control of neglected tropical diseases (NTDs), emphasizing its impact on research funding and healthcare services in low and middle-income countries (LMICs). Significant reductions in R&D funding were observed, particularly for diseases like mycetoma, trachoma and Buruli ulcer. Pandemic-related restrictions caused delays in mass drug administration, vaccination programs and diagnostics, leading to setbacks in disease elimination goals. The pandemic exacerbated poverty, further straining healthcare access and nutrition in vulnerable communities. The study highlights the importance of global cooperation and increased investment to overcome obstacles and realign with the NTD elimination goals.

2.3.4 A robust optimization model for multi-objective blood supply chain network considering Scenario Analysis under uncertainty: a multi-objective approach (Fariman *et al*., 2024)

The document addresses the management of blood supply chains during crises, proposing a robust optimization model to minimize costs and shortages while maximizing the availability of blood products. Incorporating scenario analysis and multi-objective optimization, the model accounts for uncertainties in demand and supply. It uses mathematical programming to allocate blood efficiently, considering both temporary and permanent facilities. Validated through a case study in Iran, the model highlights the significance of adaptability and resilient blood supply chain management for crisis scenarios.

2.3.5 Lessons from the COVID-19 Pandemic: Promoting Vaccination and Public Health Resilience, a Narrative Review (Pennisi *et al*., 2024)

The document highlights the need for resilient public health systems to address health emergencies effectively. It reflects on lessons from the COVID-19 vaccination campaign, identifying logistical, economic, sociocultural and policy challenges that impact vaccine uptake, particularly in resource-limited settings. Emphasizing the importance of supply chain enhancement, community engagement, effective communication and equitable healthcare access, it also underscores the promise of mRNA vaccine technologies, contingent on public trust. Strategies such as partnerships with local leaders, tailored messaging and digital tools are proposed to combat vaccine hesitancy. The paper calls for evidence-based public health strategies, global cooperation and investment in infrastructure like cold chain systems to improve preparedness for future crises and public health outcomes (figure 5).

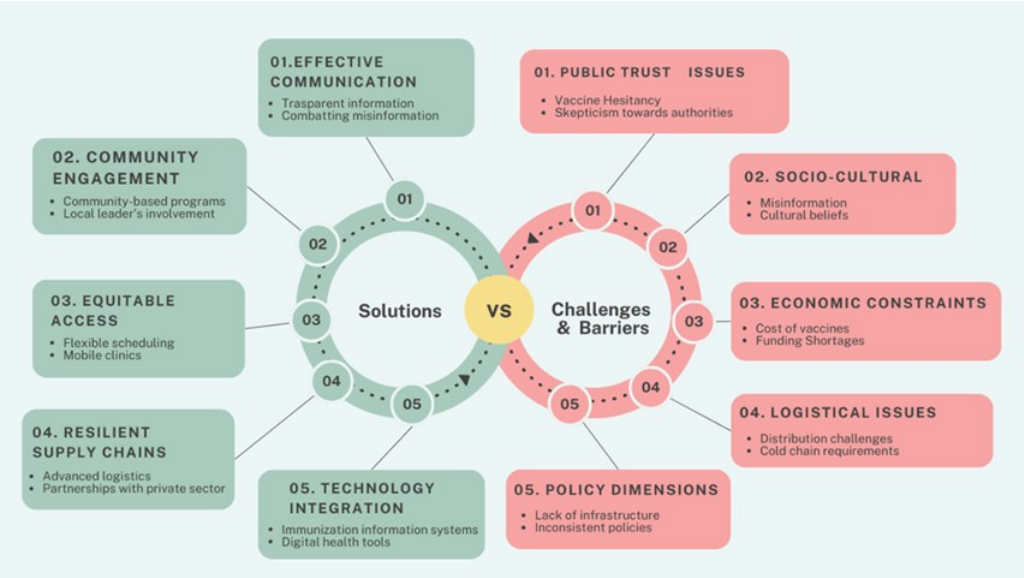

FIGURE 5: CHALLENGES, OBSTACLES AND POTENTIAL SOLUTIONS IDENTIFIED FROM THE COVID-19 PANDEMIC, SOURCE (PENNISI ET AL., 2024)

2.3.6 Modelling supply chain Visibility, digital Technologies, environmental dynamism and healthcare supply chain Resilience: An organisation information processing theory perspective (Tiwari *et al*., 2024)

The document examines how digital technologies (DT) and supply chain visibility (SCV) contribute to improving healthcare supply chain resilience (HSCR), especially in times of crises such as the COVID-19 pandemic. Grounded in the Organizational Information Processing Theory (OIPT), it analyzes 137 survey responses to demonstrate how SCV serves as a foundational resource for developing digital capabilities. These capabilities enable real-time insights into inventory, production schedules and transportation status, improving decision-making and adaptability in dynamic environments. The study highlights the moderating role of environmental dynamism (ED), emphasizing that in highly uncertain contexts, DT are critical for maintaining supply chain efficiency. Insights from this research provide actionable recommendations for healthcare managers and policymakers to leverage SCV and DT for a more resilient and efficient supply chain, ensuring the availability of vital medical supplies and better patient outcomes.

2.4 DIGITAL TECHNOLOGIES FOR RESILIENCE AND RISK MANAGEMENT IN HEALTHCARE SUPPLY CHAINS

In this paragraph, the articles grouped within this class will be reviewed individually, emphasizing the unique contributions of each paper to the topic of resilience and risk management in healthcare supply chains. The discussion will highlight how digital technologies, such as IoT, Blockchain and AI, are being leveraged to enhance supply chain resilience and mitigate risks, particularly in crisis situations like pandemics. Every article offers significant perspectives on how these technologies contribute to enhancing effectiveness in operations, assuring the availability of resources and beefing up the security and adaptability of healthcare supply networks.

2.4.1 A Systematic Review on the Use of AI-Powered Cloud Computing for Healthcare Resilience (Maguraushe *et al*., 2024)

The paper explores the role of AI-powered cloud computing in enhancing healthcare resilience during crises like pandemics. It highlights benefits such as real-time monitoring, advanced data analysis, predictive modeling and personalized treatment plans, which improve patient care and operational efficiency. AI-powered cloud platforms support telehealth services, including remote monitoring, virtual consultations and telemedicine, ensuring continuous care even during disruptions. These platforms are scalable, promote collaboration, enhance interoperability and maintain data security through robust measures against potential threats. By integrating these technologies, healthcare providers can better adapt to and recover from emergencies, ensuring improved health outcomes.

2.4.2 Analyzing barriers and strategies in digital transformation for resilient SC in healthcare using AHP and MABAC under uncertain environment (Seker & Aydin, 2024)

The document examines the barriers to digital transformation (DT) in healthcare supply chains (SC) in developing countries and proposes strategies to enhance resilience. Key challenges include limited managerial support, lack of digital culture and concerns over data safety. To address these, the study suggests fostering executive support, promoting digital culture and strengthening data privacy measures. Using a hybrid Multi-Criteria Decision-Making (MCDM)

method with Analytical Hierarchy Process (AHP) and MABAC under a picture fuzzy (PiF) environment, the research evaluates these barriers and strategies. Insights are provided for healthcare managers and policymakers to develop resilient supply chains, improving efficiency, reliability and patient care.

2.4.3 Resilience capabilities of healthcare supply chain and supportive digital technologies (Furstenau *et al*., 2022)

The document examines how digital technologies (DT) enhance healthcare supply chain (HSC) resilience through proactive and reactive capabilities. Based on interviews with 15 HSC managers from eight healthcare organizations and document analysis, the study identifies 14 key DT, such as big data analytics and remote inventory monitoring, which support collaborative planning and strategic alliances. It introduces a framework linking DT to the four resilience potentials: anticipating, responding, monitoring and learning, mediated by organizational capabilities. The research provides actionable insights for managers and policymakers to design resilient HSC, improving adaptability, performance and stability in response to disruptions.

2.4.4 When Wireless Communication Responds to COVID-19: Combating the Pandemic and Saving the Economy (Saeed *et al*., 2020)

The document highlights the critical role of wireless communication technologies in combating COVID-19 and supporting the global economy (figure 6). These technologies enable virus monitoring, healthcare automation (e.g., 5G medical robots) and virtual education with augmented and virtual reality tools. It emphasizes digital inclusiveness through solutions like tethered drones, high-altitude platforms and satellite networks to connect underserved areas. Key challenges include privacy, security and misinformation, underlining the need for robust cybersecurity measures. The document concludes that wireless technologies, pivotal during the pandemic, will remain essential for future resilience and sustainability.

FIGURE 6: HOW WIRELESS TECHNOLOGIES ARE APPLIED IN THE COVID-19 PANDEMIC, SOURCE (SAEED ET AL., 2020)

2.4.5 Redefining HCC Surveillance in India: A Call for Innovative and Inclusive Strategies (Yelsangikar & Patil, 2024)

The document discusses the rising incidence of hepatocellular carcinoma (HCC) in India and the need for improved surveillance strategies. While chronic HBV infection remains the leading cause, the growing prevalence of MASLD is changing the disease's epidemiology. In many instances, diagnoses occur at later stages, resulting in unfavorable outcomes. Current six-monthly surveillance using USG with or without AFP testing has limitations, particularly for MASLD patients. The document recommends adopting refined methods like tumor markers (PIVKA II) and algorithms (GALAD, GAAD), emphasizing community-based blood markers and digital technologies to reach at-risk populations. It calls for a nationwide HCC registry, upgraded centers of excellence and multidisciplinary care to improve early diagnosis and patient outcomes.

2.4.6 Securing the IoT Landscape: A Comprehensive Review of Secure Systems in the Digital Era (Siraparapu & Azad, 2024)

The document highlights the significance of strong security measures in the Internet of Things (IoT) to enhance operational efficiency, productivity and resilience against cyber threats. It emphasizes the role of IoT secure systems in optimizing processes in Industry 4.0 and applications in smart homes, healthcare and automobiles. Standards like the IoT Trust Model and emerging trends in security regulations are discussed, alongside gaps in current frameworks. Key measures include integrating security through secure coding, authentication,

encryption, over-the-air updates and leveraging AI for proactive threat detection. Collaborative efforts among stakeholders are critical to establishing comprehensive security frameworks, ensuring data integrity, privacy and fostering trust in interconnected environments.

2.4.7 Secured Blockchain Technology for Medical Supply Chain (SB-MSC) (Sumalatha *et al.*, 2024)

The document outlines a secured blockchain technology framework for medical supply chains (figure 7), integrating IoT-based sensors to monitor environmental conditions (e.g., temperature, humidity) and using blockchain to securely store and transmit data. Smart contracts ensure authorized access for stakeholders, maintaining data integrity. The system includes algorithms for rerouting deliveries if quality issues arise and for prioritizing drug distribution to ensure timely delivery. By combining IoT and blockchain, the framework enhances supply chain resilience, transparency and efficiency, ensuring the integrity of medical supplies.

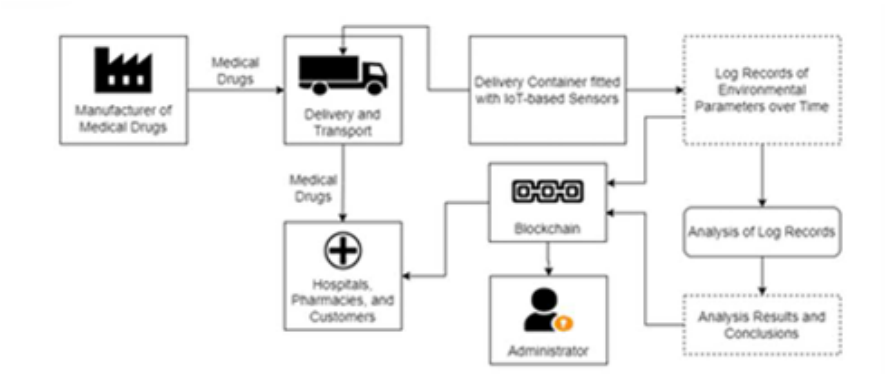

FIGURE 7: BLOCKCHAIN-BASED SECURITY FOR THE MEDICAL SUPPLY CHAIN, SOURCE (SUMALATHA ET AL., 2024)

2.4.8 Reshaping healthcare supply chain using chain-of-things technology and key lessons experienced from COVID-19 pandemic (Sathiya *et al.*, 2023)

The document highlights vulnerabilities in healthcare supply chains (HSC) exposed by COVID-19 (figure 8) and emphasizes the necessity for adaptable systems. It underscores the role of Chain of Things (CoT) technology, integrating IoT and blockchain, in improving real-time monitoring, secure data transmission and transparency. IoT sensors guarantee the quality of medical supplies, while blockchain enables secure data and smart contracts. Five areas for improvement are identified: resilience, localization, reverse logistics, end-to-end visibility and digitalization. The document also stresses advanced digital technologies like AI, machine learning and robotics for a robust and adaptable supply chain. By

leveraging CoT and digital transformation, HSC can better handle disruptions and improve consignment of care.

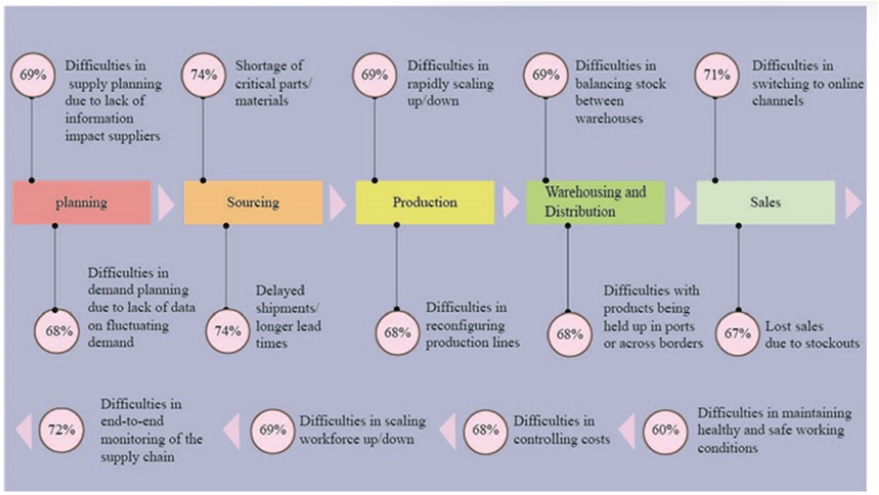

FIGURE 8: PERCENTAGE OF ORGANIZATIONS THAT STRUGGLED WITH SIGNIFICANT SUPPLY CHAIN ISSUES DURING THE PANDEMIC, SOURCE (SATHIYA ET AL., 2023)

2.4.9 A review of smart contract-based platforms, applications, and challenges (Sharma *et al*., 2023)

The document reviews smart contract-based platforms, applications and challenges, highlighting their role in extending blockchain technology beyond cryptocurrencies to areas like IoT, healthcare, supply chains and voting. Platforms such as Ethereum, Hyperledger Fabric and Cardano are evaluated according to their consensus mechanisms, data models and use cases. The use of smart contracts in areas such as insurance (figure 9), user access management and cloud computing are explored, alongside their advantages and limitations. Challenges, including code readability, execution efficiency and privacy, are addressed with solutions such as verification techniques and human-readable execution. The document emphasizes the significance of self-executing contracts in enhancing efficiency and security across various sectors and outlines directions for future research.

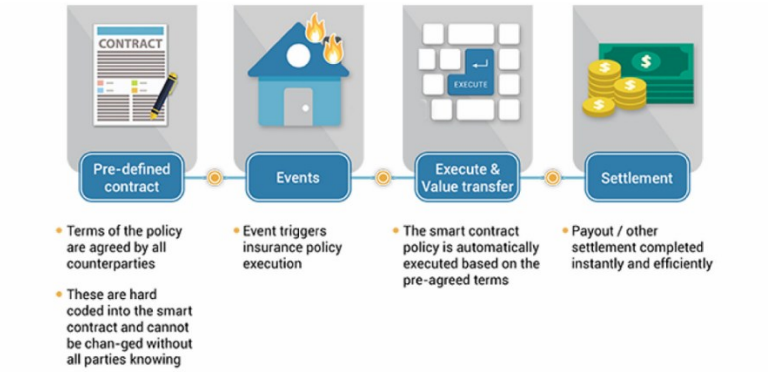

FIGURE 9: INSURANCE SYSTEM POWERED BY SMART CONTRACTS, SOURCE (SHARMA ET AL., 2023)

2.4.10 IoE Security Risk Analysis in a Modern Hospital Ecosystem (Jimo *et al.*, 2023)

The document analyzes the security risks of the Internet of Everything (IoE) in hospital ecosystems, emphasizing the need to address vulnerabilities to protect patient safety and data privacy. It identifies risks such as data breaches, cyberattacks and device vulnerabilities, which threaten both patient care and hospital operations. Privacy challenges arise from increased interconnectivity, making unauthorized data access a significant concern. The document highlights solutions like robust cybersecurity measures, regular security assessments and staff security training. Advanced technologies such as artificial intelligence (AI) and machine learning (ML) are recommended to detect and mitigate threats in real time. In conclusion, it stresses the importance of comprehensive strategies to enhance IoE security, ensuring safe and reliable hospital operations.

2.4.11 IoT-driven Smart Packaging for Pharmaceuticals: Ensuring Product Integrity and Patient Safety (Raman *et al.*, 2023)

The document discusses the development of IoT-driven smart packaging in the pharmaceutical industry (figure 10) to ensure product integrity, prevent tampering and improve patient safety. It incorporates sensors (e.g., temperature, humidity, light, tamper detection, GPS, accelerometers, RFID) to monitor and analyze environmental and handling conditions in real-time, reducing risks of product deterioration. This intelligent packaging enhances supply chain visibility and medication management by ensuring effective and legitimate pharmaceuticals reach patients. Key benefits include maintaining optimal storage conditions, detecting tampering or security breaches, providing GPS-based transparency

and improving inventory management with RFID tags. The study also highlights challenges and opportunities in adopting these technologies, emphasizing their transformational potential to enhance healthcare outcomes and supply chain efficiency.

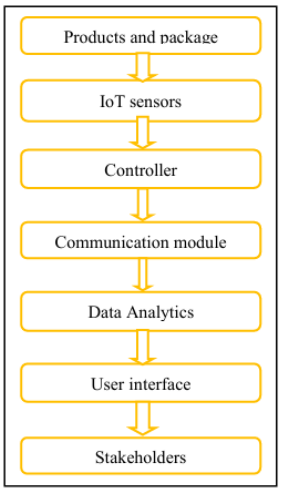

FIGURE 10: SYSTEM WORKFLOW, SOURCE (RAMAN ET AL., 2023)

2.4.12 Revolutionizing Industries Through IoT, Blockchain and AI Integration (Aruna *et al.*, 2023)

The document examines the transformative potential of integrating IoT, Blockchain and AI across industries like supply chain management, healthcare and smart cities. It highlights how these technologies create decentralized, secure and intelligent systems, enabling real-time tracking, secure data exchange, optimized urban systems and enhanced decision-making. The integration improves efficiency and transparency, addresses fraud risks and supports innovations like predictive maintenance and smart contracts. Challenges include data privacy, scalability, interoperability, regulatory compliance and cost, requiring focused research, partnerships and frameworks. The study underscores the need for responsible and ethical implementation to fully harness these technologies' potential for innovation, efficiency and security.

2.4.13 Blockchain Technology: Opportunities & Challenges (Bilal *et al.*, 2022)

The document provides a comprehensive overview of blockchain technology, emphasizing its transformative potential across industries like cryptocurrency, supply chain management, healthcare, financial services and IoT (figure 11). It

discusses blockchain's key characteristics—security, immutability, decentralization and transparency—and its ability to enable secure, intermediary-free transactions through components like nodes, ledgers, wallets, hashes and consensus protocols (e.g., PoW, PoS). Blockchain deployment models, including public, private, consortium and hybrid, are outlined alongside various applications, such as improving data security in healthcare, enhancing transparency in supply chains and reducing fraud in financial services. Despite its advantages, blockchain faces challenges like scalability, high energy consumption, privacy concerns and regulatory gaps. Addressing these issues and integrating blockchain with technologies like AI and cloud computing could unlock its full potential for innovation and efficiency across sectors.

FIGURE 11: GLOBAL BLOCKCHAIN EXPENDITURE, SOURCE (BILAL ET AL., 2022)

2.4.14 Securing Internet of Things devices by enabling Ethereum blockchain using smart contracts (Patruni & Saraswathi, 2022)

The document examines the integration of Ethereum blockchain technology with IoT devices to address security vulnerabilities and privacy concerns arising from the rapid expansion of IoT. By implementing smart contracts, it secures IoT devices and records authenticated data on an immutable blockchain. Key security features include decentralization, consensus mechanisms and cryptographic protection. Tools like Ganache, Truffle and Metamask are used for development. The proposed methodology (figure 12) incorporates three components—cloud, blockchain and IoT devices—with fog nodes acting as blockchain nodes. Security services provided include data integrity through hash values, confidentiality via public-key cryptography, availability ensured by smart contracts, scalability through peer-to-peer networks and protection against DoS attacks.

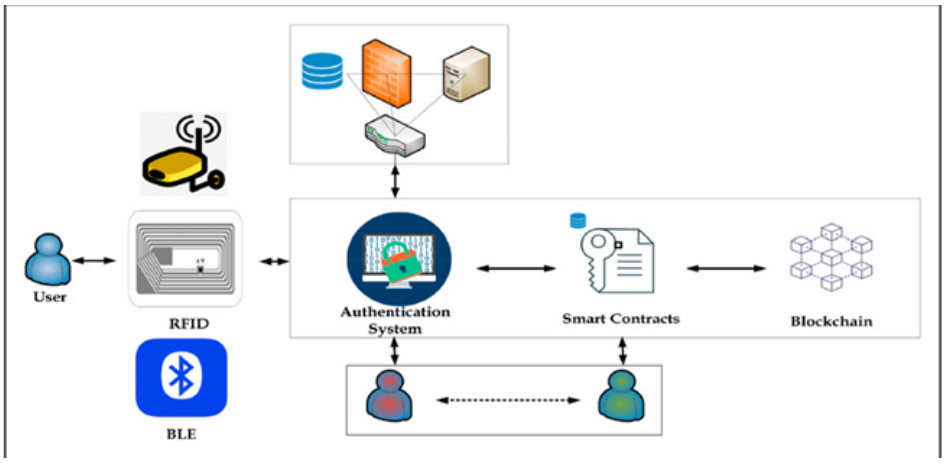

FIGURE 12: SUGGESTED SYSTEM ARCHITECTURE, SOURCE (PATRUNI ET AL., 2022)

2.4.15 Systematic Analysis of Risk Associated with Supply Chain Operations Using Blockchain Technology (Khan *et al.*, 2022)

The document examines how blockchain technology addresses risks in supply chain operations (figure 13). Its decentralized, immutable and transparent nature secures transactions, ensures data integrity and prevents tampering without intermediaries. Smart contracts automate agreements, reducing human error and fraud, while cryptographic techniques protect data from unauthorized access. Blockchain applications include product tracking, authenticity verification and improved transparency, enhancing efficiency and resilience across supply chains.

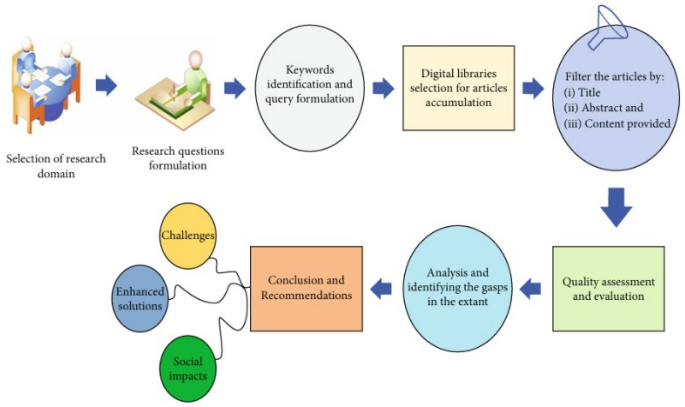

FIGURE 13: RESEARCH APPROACH FOR THE PROPOSED SYSTEMATIC LITERATURE REVIEW, SOURCE (KHAN ET AL., 2022)

2.4.16 Internet of Things (IoT) in high-risk Environment, Health and Safety (EHS) industries: A comprehensive review (Thibaud *et al.*, 2018)

The document highlights the transformative potential of IoT in high-risk Environment, Health and Safety (EHS) industries, focusing on healthcare. IoT applications address the needs of an aging population, rising chronic diseases

and the demand for better access to health records and improved services. They enhance clinical care, home care, logistics and patient safety by reducing medical errors and integrating devices like RFID and wearables. The shift toward home-centered care, higher device integration and compliance with privacy standards are key drivers of adoption. In the healthcare supply chain, IoT ensures product quality, transparency and efficient operations by optimizing processes, analyzing data and maintaining integrity from production to consumption.

2.4.17 Supply chain management in the era of the internet of things (Zhou *et al*., 2015)

The paper explores how IoT is transforming supply chain management by connecting devices and sensors to enable machine-driven decision-making with minimal human input. This integration enhances transparency, traceability, adaptability and efficiency while reducing costs and risks. Technologies such as Radio Frequency Identification, wireless sensing networks and mobile applications facilitate instant tracking, inventory control and optimized operations, including warehousing, production scheduling and transport route design. Applications span sectors such as healthcare, pharmaceuticals, retail and food traceability. Notable examples include IoT-enabled Supply Hubs improving resource use and RFID-based systems optimizing production. Collaborative warehousing and IT-enabled decision-making further enhance supply chain performance. Challenges like the necessity for data-driven models and robust IT infrastructure are also highlighted.

2.4.18 A Bi-objective location-routing model for the healthcare waste management in the era of logistics 4.0 under uncertain (Govindan *et al*., 2024)

The study explores the application of Industry 4.0 technologies can be utilized to manage contagious medical waste by employing a decision support system (DSS) that relies on a bi-objective mixed-integer linear programming (MILP) model. Incorporating electric autonomous vehicles, IoT, GNSS and RFID-tagged waste bags, the model improves waste collection efficiency, optimizes routes and reduces contamination risks. Validated in seven hospitals in Karaj, Iran, the system addresses challenges like excessive waste, inefficient routes and toxic exposure by enabling real-time data collection and decision-making. RFID and

GNSS technologies enhance transparency and security, while the study underscores the need to bridge theoretical and practical gaps to fully leverage Logistics 4.0 advancements.

2.4.19 The Drivers of Complexity in Inventory Management Within the Healthcare Industry: A Systematic Review (Al Khatib *et al*., 2024)

The document examines the intricacies of healthcare inventory control, emphasizing the improvement of efficiency and resilience in supply chains. It highlights the transformative role of technologies such as AI, machine learning, IoT, Autonomous Mobile Robots, Radio Frequency Identification and blockchain in enabling predictive analytics, real-time tracking and supply chain transparency. Automation reduces human error, while cloud-based systems like SMART logistics enhance adaptability and coordination across sites. The document emphasizes the importance of inventory management in ensuring timely access to resources, minimizing waste and optimizing allocation. It also addresses challenges like demand uncertainties, vendor management and environmental concerns, proposing strategies such as early detection systems, flexible healthcare models and fostering agility to overcome these obstacles.

2.4.20 A fuzzy optimization-oriented decision support model to examine key industry 4.0 strategies for building resilience against disruptions in a healthcare supply chain (Kayhan *et al*., 2024)

The document explores how Industry 4.0 technologies enhance the resilience of healthcare supply chains (HSCs). Employing a two-stage approach that incorporates Fermatean fuzzy numbers (FFNs), the Best Worst Method (BWM) and goal programming (GP), the study evaluates and prioritizes strategies based on SCOR resilience factors. The results highlight the Internet of Things (IoT) as the most effective strategy overall, followed by Blockchain and Digital Twin technologies. IoT leads in the Fulfill phase, Digital Twin excels in the Plan and Transform phases, Blockchain is most effective in the Order and Return stages and Machine Learning excels in the Source process. These insights provide decision-makers with guidance to optimize digital investments and strengthen HSC resilience against disruptions.

2.4.21 Exploring the effect of blockchain technology on supply chain resilience and transparency: Evidence from the healthcare industry (Alabaddi *et al*., 2023)

The paper explores how blockchain technology enhances visibility in supply chains and adaptability in healthcare (figure 14). It highlights how blockchain facilitates the decentralization of management of supply chains, improving workflow efficiency and minimizing security risks. The study explores how blockchain features—such as data quality, self-executing agreements and ability to track and trace—on these outcomes, based on data from 215 healthcare professionals in Jordan. Results reveal that data quality and traceability positively influence both transparency and resilience, while smart contracts enhance transparency, but not resilience. Additionally, blockchain-driven transparency strengthens resilience, enabling more effective recovery from disruptions. These insights assist supply chain managers and stakeholders in optimizing blockchain implementation to enhance supply chain performance.

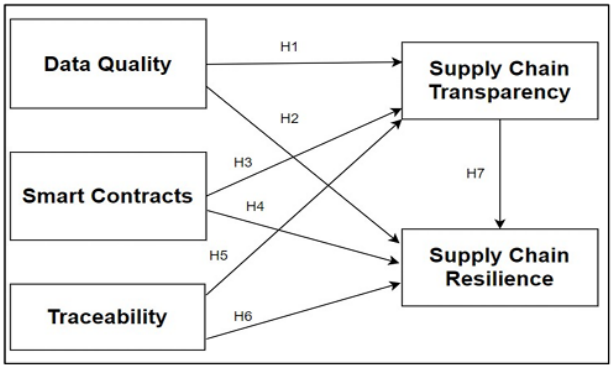

FIGURE 14: RESEARCH MODEL DEVELOPED FROM THE LITERATURE REVIEW, SOURCE (ALABADDI ET AL., 2023)

2.4.22 Identifying resilience strategies for disruption management in the healthcare supply chain during COVID-19 by digital innovations: A systematic Literature Review (Arji *et al*., 2023)

The document explores how digital technologies like AI, blockchain, big data analytics and simulation enhance the resilience of healthcare supply chains during the COVID-19 pandemic. It highlights their role in developing resilience plans to manage disruptions and mitigate impacts. While these technologies address supply chain vulnerabilities, their practical application for managing disturbances and ensuring resilience remains underexplored. The study (figure

14) emphasizes the need for further research to develop effective strategies for strengthening healthcare supply chain resilience against future disasters.

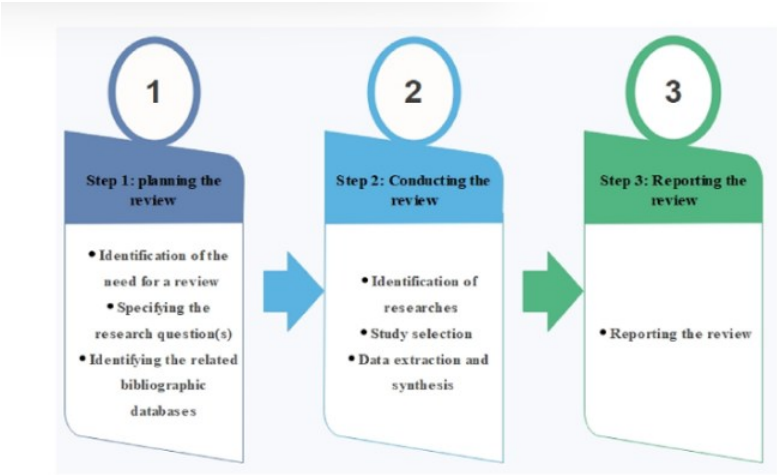

FIGURE 15: SYSTEMATIC REVIEW STEPS, SOURCE (ARJI ET AL., 2023)

2.4.23 Improving End-to-End Traceability and Pharma Supply Chain Resilience using Blockchain (Sim *et al.*, 2022)

The paper examines how blockchain technology, particularly Hyperledger Fabric, improves the pharmaceutical supply chain by enabling secure, real-time data sharing and enhancing traceability and resilience. The COVID-19 pandemic underscored the necessity for improved transparency and enhanced connectivity among stakeholders throughout the supply chain. The study showcases the adoption of eZTracker, an industry-grade blockchain solution offering six features: anti-counterfeit verification, product recall management, cold chain monitoring, electronic product information, real-time verification and data transparency. Integrating blockchain with warehouse platforms, a mobile app and an interactive dashboard boosts supply chain efficiency and security. However, challenges such as limited serialization in Asia and interoperability issues must be addressed. Collaboration among pharmaceutical manufacturers is essential to breaking data silos and maximizing blockchain's potential.

2.4.24 At the Epicenter of COVID-19–the Tragic Failure of the Global Supply Chain for Medical Supplies (Bhaskar *et al.*, 2020)

The study examines the shortcomings of the global supply chain during the COVID-19 pandemic, focusing on acute shortages of essential medical supplies and PPE, which raised concerns about health system sustainability and caused fear among frontline workers. It emphasizes the need for improved coordination,

integration and management to mitigate pandemic impacts. The authors propose a governance model leveraging advanced analytics and blockchain to improve manufacturing efficiency and crucial stockpile profiling (figure 16). This model supports health efforts for the public during emergencies, by minimizing dangers to healthcare personnel and reinforcing preparedness for future outbreaks. The document also emphasizes the importance of sustaining adequate stockpiles to address low initial supplies and sudden demand surges.

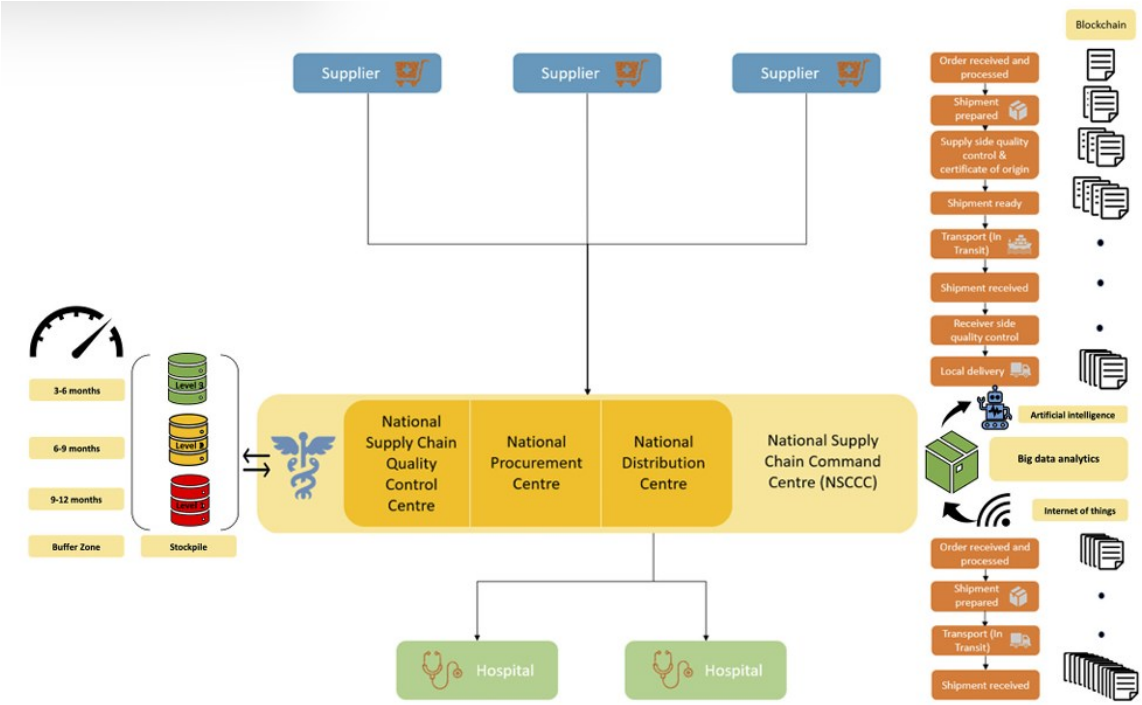

FIGURE 16: DIAGRAM OF THE GLOBAL SUPPLY CHAIN MODEL FOR HEALTHCARE SUPPLIES WITH BLOCKCHAIN AS THE CONNECTOR, SOURCE (BHASKAR ET AL., 2020)

2.4.25 Blockchain adoption opportunities in healthcare sector (Althobaiti, 2020)

The document examines the transformative potential of blockchain technology in the healthcare industry, emphasizing its decentralized, secure and transparent nature. Key applications include:

- medical data management, where blockchain ensures secure sharing of patient information while maintaining privacy,
- medicine supply chains, enhancing traceability and preventing drug counterfeiting;
- telemedicine, offering a trusted platform for remote monitoring, diagnosis and treatment;

- medical analytics, enabling secure data sharing and collaboration for research and predictive analytics.

These applications highlight blockchain's ability to reduce costs, improve security and enhance resilience in healthcare.

2.4.26 Leveraging Blockchain Technology to Establish a Transparent and Counterfeit-Resistant Pharmaceutical Supply Chain (Kumarswamy & Sampigerayappa, 2024)

The paper addresses medicine counterfeiting by proposing a blockchain-based solution to enhance the transparency and security of the pharmaceutical supply chain (PSC), a critical component of the Internet of Medical Things (IoMT). It highlights challenges in the PSC, including complexity, accountability issues and risks from counterfeit drugs and mismanagement of temperature-sensitive medications. The proposed Ethereum-based framework maintains an immutable record of drug movements and automates quality control through smart contracts, ensuring drug validity and issuing alerts for temperature deviations. A prototype of the framework demonstrated scalability and safety, significantly enhancing transparency and efficiency within the PSC to safeguard patient safety and improve public health outcomes.

2.4.27 Blockchain Technology in Pharmaceutical Industry: A Review of Recent Research Articles on PubMed (Pareek *et al*., 2024)

The document examines blockchain technology's transformative role in the pharmaceutical sector, focusing on its potential to improve clearness, safety and efficiency via innovations like self-executing contracts and decentralized applications (dApps). These tools automate operations, strengthen product integrity and reduce counterfeit medication risks. Highlighting research from 2015 to 2023, the review emphasizes blockchain's capacity to improve regulatory approvals, streamline processes by reducing intermediaries and enhance patient-centricity. Applications such as Medledger and chaincodes are discussed for their role in drug tracing and supply chain security. Additionally, the document presents a private network model using Hyperledger Fabric, illustrating blockchain's broader potential beyond traditional applications.

2.4.28 Healthcare Applications Using Blockchain With a Cloud-Assisted Decentralized Privacy-Preserving Framework (Deebak & Hwang, 2023)

The paper presents the CA-DPPF framework, which integrates blockchain technology and key agreement mechanisms to enhance privacy and security in healthcare applications. By addressing challenges in distributing confidential data over public networks, this decentralized approach ensures secure data transmission, storage, and transfer using elliptic-curve digital signature algorithms (EC-DSA). The framework also employs the Proof of Trusted Authority (POTA) consensus mechanism to safeguard medical data in cloud storage. Additionally, CA-DPPF improves transaction efficiency, reduces latency, and increases throughput, optimizing service utilization in healthcare supply chain management.

2.4.29 The impact of healthcare 4.0 technologies on healthcare supply chain performance: Extending the organizational information processing theory (Saha & Rathor, 2024)

The document examines the role of healthcare 4.0 technologies, including big data analytics, artificial intelligence (AI) and blockchain, in enhancing hospital supply chain processes and performance (figure 17). Using organizational information processing theory (OIPT) and survey data from 255 hospital managers in India, the study highlights the significant impact of these technologies on operations, innovations and risk management. It also reveals that the type of healthcare organization (private or public) influences the relationship between healthcare 4.0 technologies and supply chain processes. The findings provide evidence to help healthcare professionals optimize these technologies and integrate digital supply management into health system development.

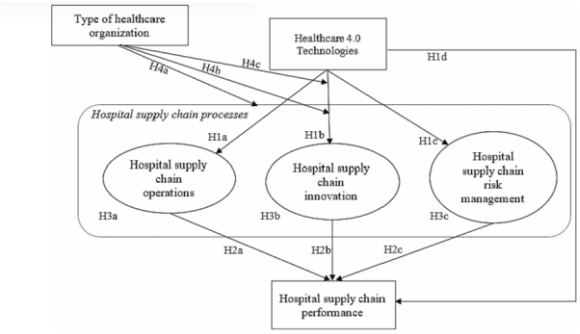

FIGURE 17: THEORETICAL STRUCTURE, SOURCE (SAHA ET AL., 2024)

2.4.30 Supply chain risk factor assessment of Indian pharmaceutical industry for performance improvement (Sharma *et al*., 2024)

The paper aims to enhance the performing feature of the Indian pharmaceutical industry by recognizing and assessing dangers through the use of the fuzzy synthetic evaluation (FSE) method. It evaluates risks based on probability of occurrence, impact, unpredictability and urgency (figure 18), highlighting counterfeit drugs, demand fluctuations and poor partner service as the most critical issues. The main categories—demand, financial and logistics—contribute to a moderate to high risk level. The study emphasizes adopting technologies like blockchain and artificial intelligence to mitigate risks, such as counterfeit drugs and demand fluctuations and calls for improved risk management strategies to enhance efficiency and responsiveness in the industry.

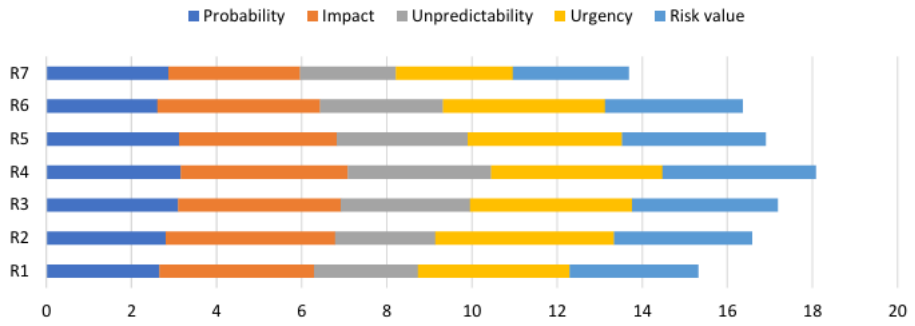

FIGURE 18: EVALUATION OF THE KEY RISKS, SOURCE (SHARMA ET AL., 2024)

2.4.31 Blockchain based Health Records Management for Diabetes Patients: Real-World Applications (Sangwan Poonam, 2024)

The document highlights blockchain's transformative role in managing health records for diabetic patients by ensuring privacy, security and accessibility for authorized providers. It facilitates interoperability, enabling healthcare providers to transparently access and update medical records. Additionally, blockchain secures the supply chain of diabetes medications and devices, preventing counterfeit products and ensuring authenticity. In emergencies, the system provides first responders with critical patient information, even when communication is not possible, enhancing care delivery and safety.

2.4.32 Digitalization and the Medical Supply Chain Management: Systematic Literature Review and Bibliometric Analysis (Hiatt, 2024)

The paper explores the impact of digitalization on the medical supply chain, emphasizing how technologies like blockchain and RFID enhance performance, efficiency and sustainability. Through a systematic literature review (figure 19) and bibliometric analysis, the study identifies key trends and research gaps, focusing on reducing costs, addressing drug shortages or oversupplies and improving resource management. It highlights the pandemic's role in intensifying supply chain complexity and the importance of reverse logistics and sustainability. Digitalization revolutionizes supply chains by enhancing connectivity, visibility and patient satisfaction while fostering integrated healthcare systems.

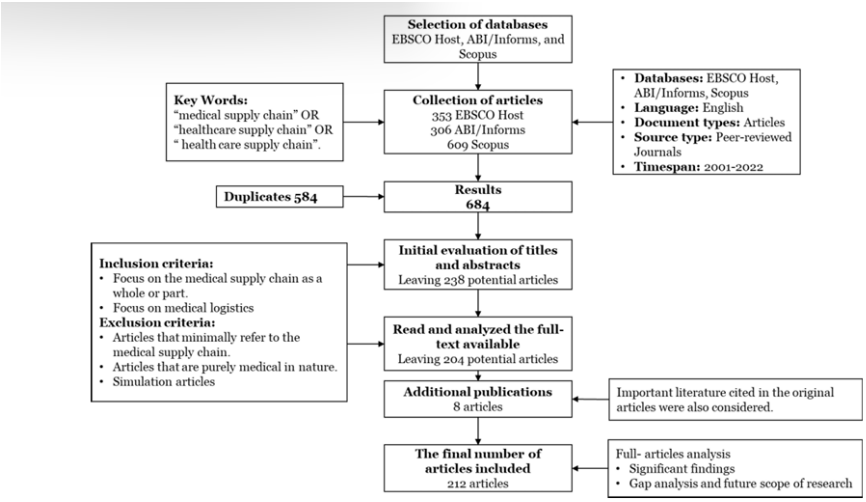

FIGURE19: RESEARCH PROCESS FOR THE SYSTEMATIC LITERATURE REVIEW, SOURCE (HIATT ET AL., 2024)

2.4.33 The Utilization of Blockchain for Data Security for the Chronic Pain Physician (Kruger *et al*., 2024)

The document examines how blockchain technology (figure 20) enhances data security in healthcare, focusing on chronic pain management. It highlights blockchain's decentralized, secure and immutable nature, ensuring transparency and data privacy. Smart contracts automate and securely manage implantable neuromodulation devices, while blockchain improves pharmaceutical supply chain integrity to prevent counterfeit medications. Despite challenges like transaction speed, blockchain offers promising solutions for healthcare security and quality improvement, with applications extending beyond chronic pain management to the wider medical sector.

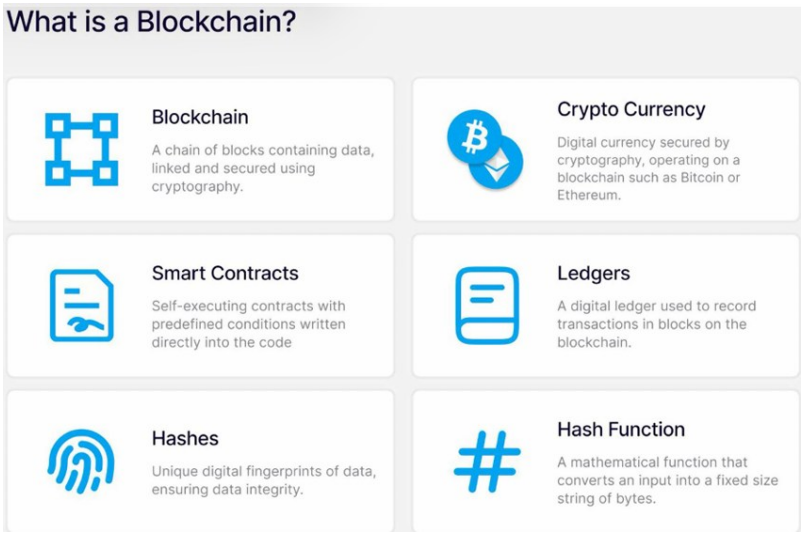

FIGURE 20: AN INFOGRAPHIC HIGHLIGHTING KEY BLOCKCHAIN COMPONENTS (COURTESY OF BLOQ, INC.), SOURCE (KRUGER ET AL., 2024)

2.4.34 Designing and implementing a resilient immutability mechanism for enhanced supply chain management in E-healthcare systems (Singla *et al.*, 2024)

The paper proposes the Immutable and Decentralized Pharma (IDP) model (figure 21), which leverages blockchain technology and self-executing contracts to enhance the safety and efficiency of pharmaceutical supply chains. Through activating comprehensive tracking and assuring data privacy, transparency and genuineness, the IDP model addresses challenges inherent in centralized systems. Tests on the Polygon blockchain network confirm the model's viability and security in a collaborative setting, offering a robust solution to eliminate counterfeit drugs and ensure product safety.

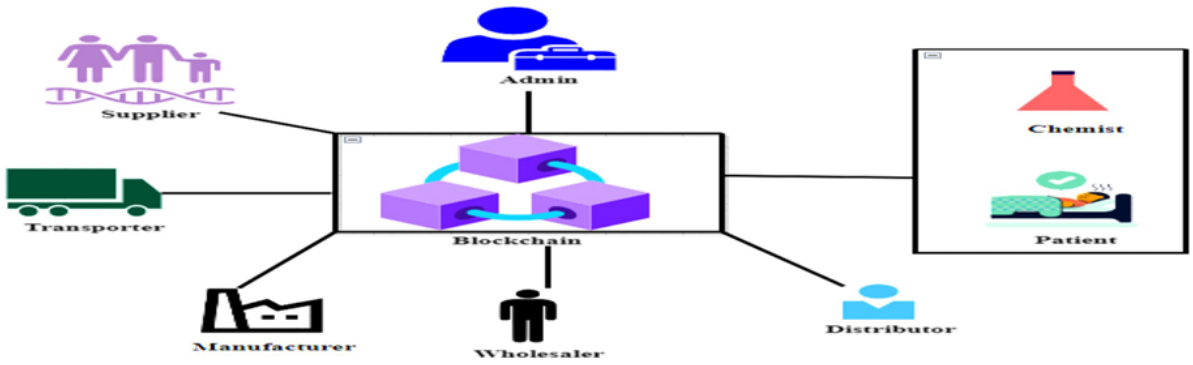

FIGURE 21: SUMMARY OF THE SUGGESTED IDP MODEL, SOURCE (DEEBAK & HWANG, 2023)

2.4.35 Leveraging Deep Learning and Blockchain for Enhanced Transparency and Traceability in the Indian Herbal Product Supply Chain (Uniyal *et al*., 2024)

The document introduces the Indian Herbal Blockchain Network (IHBN), a blockchain-based platform integrated with deep learning for image processing to improve the medicinal plant supply chain. IHBN addresses opacity and information gaps by enabling transparent traceability from source to consumer and accurate plant identification, reducing the risk of adulteration. With a deep learning model achieving 90.24% accuracy, the platform ensures reliable identification and data integrity. Its architecture consists of four nodes—Plantation Base, Trader, Manufacturer and Retailer—each responsible for recording and verifying supply chain information, fostering trust and collaboration among stakeholders (figure 22).

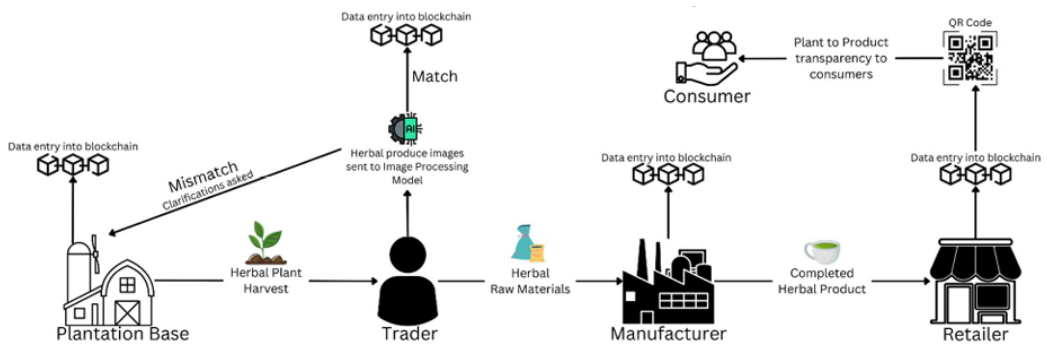

FIGURE 22: DIAGRAM OF THE PROPOSED SOLUTION'S ARCHITECTURE, SOURCE (UNIYAL ET AL., 2024)

2.4.36 Enhancing Pharmaceutical Supply Chain Management: A Blockchain-Based Model (Ettaloui et al., 2024)

The paper introduces a blockchain-based model to address the challenges of the pharmaceutical supply chain, focusing on security, privacy, transparency and authenticity. Leveraging Hyperledger Fabric and the InterPlanetary File System (IPFS), the model (figure 23) improves supply chain efficiency and integrity by mitigating risks such as counterfeit drugs and restricted access to vital information. It connects stakeholders—suppliers, manufacturers, wholesalers, distributors, pharmacies, hospitals and patients—via a user API, enabling real-time information sharing and collaboration. Smart contracts ensure regulatory compliance, control sensitive data visibility and automate traceability for pharmaceutical transactions.

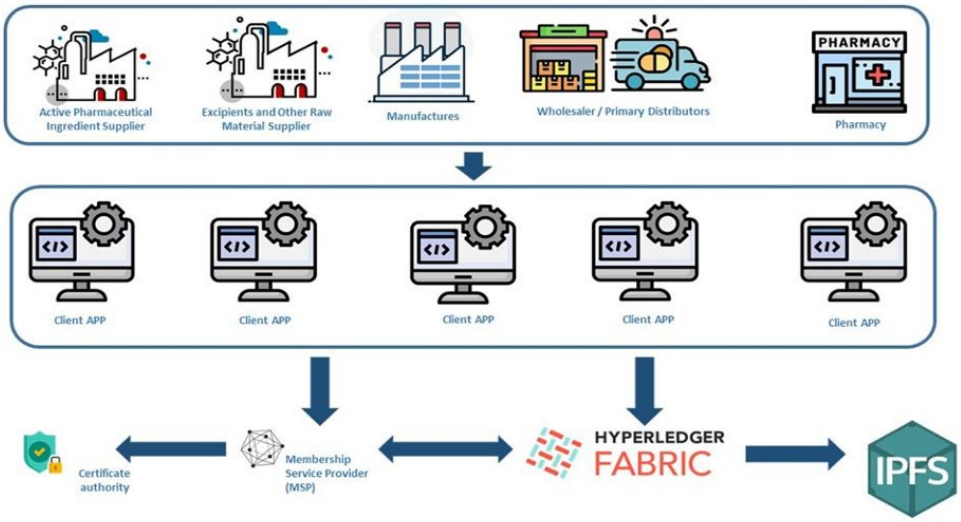

FIGURE 23: PROPOSED MODEL ARCHITECTURE AT A HIGH LEVEL, SOURCE (ETTALOUI ET AL., 2024)

2.5 CRITICAL ANALYSIS OF THE LITERATURE

It has emerged that in both 2015 and 2018, 2,38% of the 42 articles selected in this study on risk management and resilience in the healthcare supply chain were published (figure 24), while in 2020, the percentage increased by 4,76 percentage points. In 2023, the number of publications reached 16,67% and in 2024, it surpassed half of the total, reaching 59,52%. This growth could be linked to the emergence of the Covid-19 pandemic in 2020, which disrupted the healthcare supply chain and pushed the involved stakeholders to find solutions as quickly as possible, as well as to the rapid advancement of digital technologies in recent years.

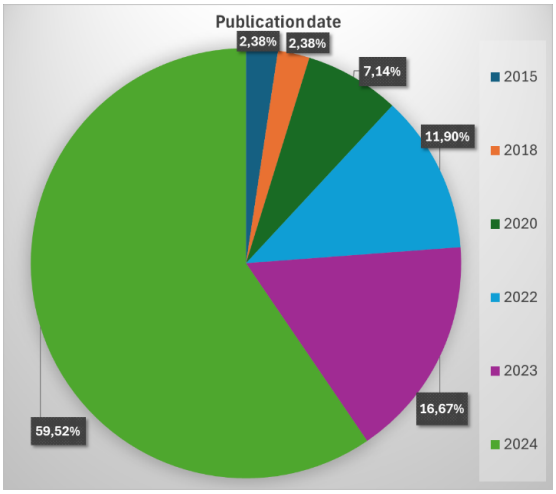

FIGURE 24: PAPERS PUBLISHED IN A CERTAIN YEAR

In the context of the healthcare industry, an author's nationality (figure 25) can significantly influence the perspective from which topics related to the healthcare supply chain are addressed. Each country has its own healthcare system, specific regulations, economic resources and available technologies that shape the way researchers analyze problems and propose solutions. Indian authors have published 38,10% of the total articles, more than double the percentage of British authors, who follow with 11,90%. Next is Iran with 7,14%, while the United States, Turkey, Saudi Arabia and Qatar each contribute 4,76%. The other countries shown in the diagram (figure 23) each account for 2,38%. These data highlight a clear predominance of research coming from India, followed by a more dispersed contribution from other countries. This may suggest that India is playing a leading role, while the other countries, although active, contribute to a lesser and less concentrated extent.

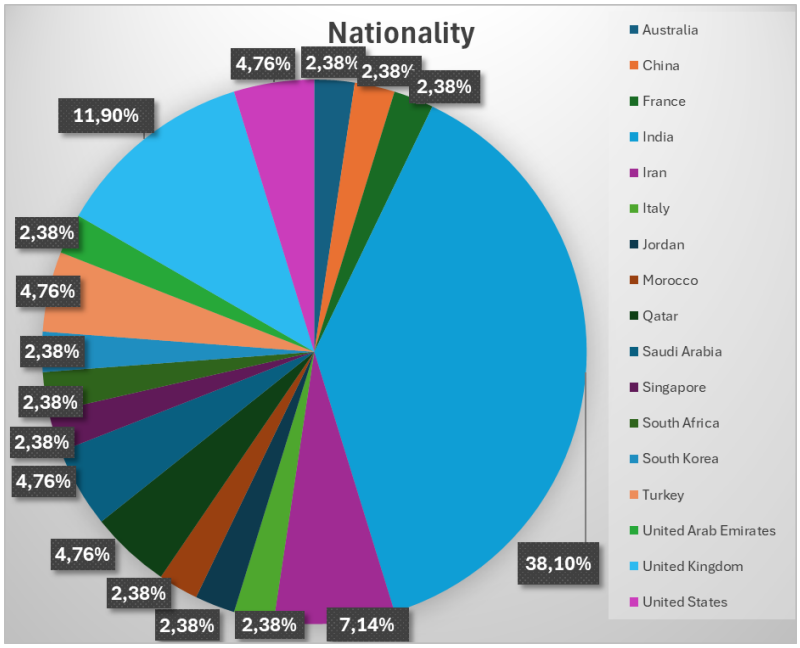

FIGURE 25: AUTHORS' NATIONALITY

As illustrated in the following diagram (figure 26), the most widely used methodology in the analyzed articles is the mixed method, representing 54,76% of the total. This is followed by the qualitative methodology with 30,95%. Finally, the quantitative methodology is the least frequent, accounting for only 14,29% of the total published articles. These data suggest a growing preference for

approaches that combine qualitative and quantitative methods, likely to leverage the strengths of both and obtain more comprehensive and reliable results.

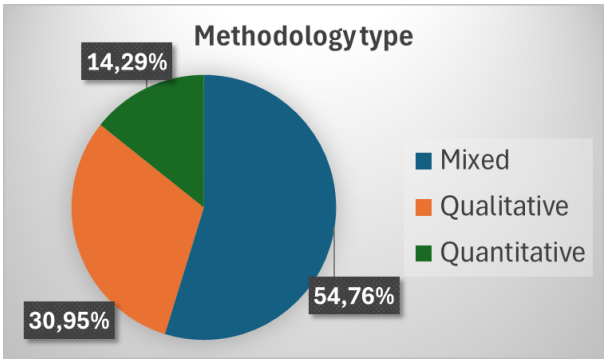

FIGURE 26: METHODOLOGY TYPE USED IN PAPER

In the diagram below (figure 27), the queries ("healthcare" AND "supply chain" AND "IoT" AND "risk"; "healthcare" AND "supply chain" AND "Blockchain" AND "risk") are those with the highest number of selected articles, accounting for 26.19% each. From this, it can be inferred that, at present, global attention is focused on risk management in the healthcare sector through the use of emerging digital technologies such as IoT and Blockchain. The second query with the highest number of examined articles, at 16.67%, is the one exploring the use of Blockchain in the context of resilience ("healthcare" AND "supply chain" AND "Blockchain" AND "resilience"). This data highlights that, in addition to risk management, there is also growing attention toward building resilience in healthcare supply chains, particularly in an era of global uncertainties such as health crises or unforeseen events. The theme of resilience thus appears to emerge as a fundamental component of research in this field, emphasizing the importance of making the healthcare system more robust and adaptable to unexpected situations. Conversely, the query ("healthcare" AND "supply chain" AND "cris*") (accounting for 14.29% of the selected articles) focuses on emergency situations, such as crises or other critical circumstances. While it is not the query with the largest number of papers, it still reflects a growing interest in managing specific crisis situations, though it does not attain the same degree of relevancy as broader topics such as risk management through technologies like IoT and Blockchain. Finally, the query regarding the use of "digital technolog*" for resilience ("healthcare" AND "supply chain" AND "digital technolog*" AND

"resilience"), with 7.14% of the papers, shows that although the subject of digital technologies is gaining traction, resilience and the ability to respond to unheralded occurrence via technological solutions are not yet as dominant a theme as risk management. The remaining queries, which cover more specific or less explored topics, each account for 2.38% of the articles, suggesting that research is primarily focused on a few key themes.

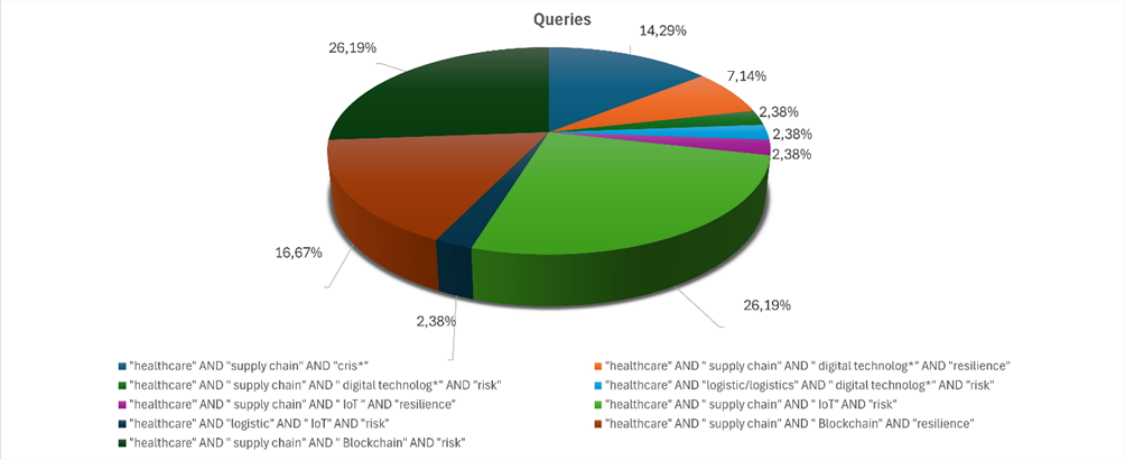

FIGURE 27: QUERIES USED FOR THE RESEARCH

The author keywords are distributed across different categories (figure 28), with a clear predominance of digital technologies, which account for 43 occurrences. This highlights how digitalization is a central and cross-cutting theme, likely due to its growing impact in various sectors. Following this, risk management appears with 14 keywords, confirming the relevance of prevention and risk mitigation in business and organizational processes. Healthcare and supply chain come next, with 12 and 11 occurrences, respectively, indicating that while they are significant sectors, their weight in the analysis is lower compared to digital technologies. Finally, the least represented category is resilience, with only 4 author keywords, which could suggest either a still limited interest in this topic or a more cross-disciplinary approach to its discussion compared to the other categories.

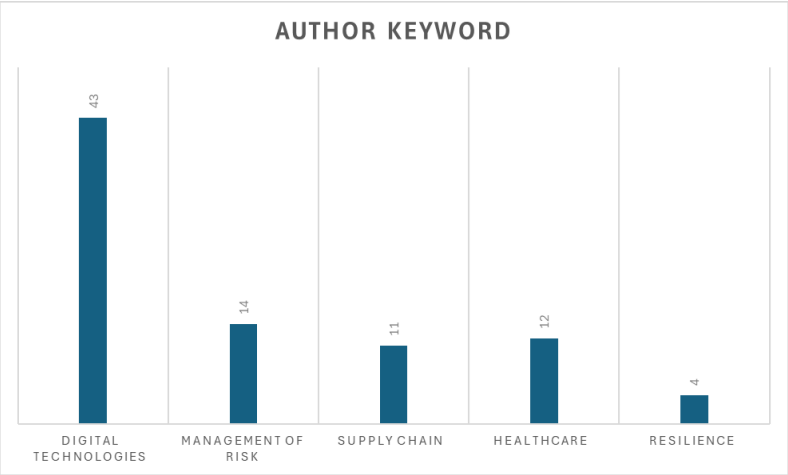

FIGURE 28: CATEGORIES OF AUTHOR KEYWORDS

In the examined articles, various study methodologies have been applied (figure 29). The Systematic Literature Review (SLR) is the most frequently used, appearing in 28 articles, followed by empirical research in 21, case study in 16 and comparative analysis in 15. This highlights a strong focus on critically analyzing existing literature, suggesting that the field is still in a phase of theoretical consolidation or that there is a need to synthesize fragmented research. However, the significant presence of empirical methodologies such as empirical research and case study also indicates a concrete interest in practical applications and real data collection. Next, conceptual framework and simulation model development are mentioned in 13 articles, while literature review appears in 11, demonstrating that, alongside systematic reviews, there is room for the development of conceptual frameworks and simulation models. Bibliometric analysis and optimization model development follow, both cited in 9 articles, along with mathematical model development, appearing in 6, reflecting an emphasis on analytical and quantitative tools to support complex decision-making. Other methodologies include citation network analysis, conceptual framework development, Multi-Criteria Decision-Making Model (MCDM), prediction model and survey, each present in 5 articles, as well as empirical model study and Structural Equation Modeling (SEM), both cited in 4 articles. The presence of tools such as MCDM and decision-making models underscores the importance of structured analysis in addressing complex problems, although their use is less widespread compared to more established approaches. Finally, among the least

used methodologies, we find content analysis and scenario analysis in 3 articles, meta-analysis, semi-structured interviews and thematic analysis in 2 and finally simulations, mentioned in only 1 article. The low presence of qualitative methodologies such as content analysis and semi-structured interviews suggests a lesser emphasis on interpretative analysis compared to quantitative or systematic approaches. Moreover, the limited number of studies employing predictive models or simulations could indicate potential future developments in these areas, highlighting how the field is evolving through a balance between theoretical and applied approaches.

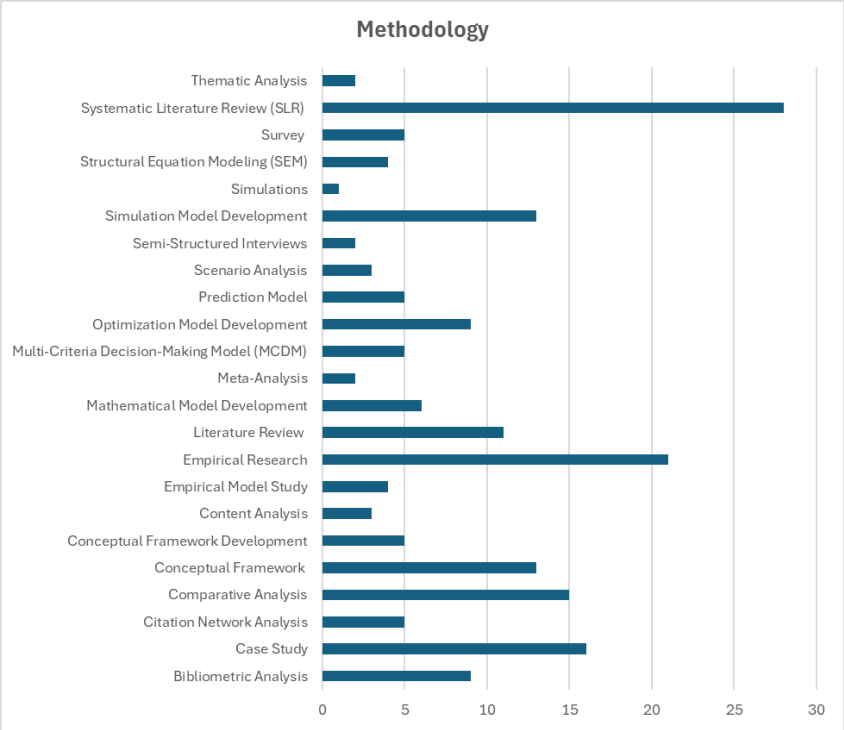

FIGURE 29: METHODOLGY OF STUDY APPLIED IN PAPERS

The graph (figure 30) shows that articles are the most common type of paper among the documents analyzed, accounting for 61.90%. This suggests that scientific publications in the examined field are predominantly original research papers, rather than secondary types. Following this, there are conference papers with 19.05%, a significant percentage indicating that research in this sector is continuously evolving and often presented at conferences. Review papers, making up 14.29%, hold an important position, suggesting a strong interest in analyzing and synthesizing existing research on specific topics. Finally, we have

book chapters and editorials, both at 2.38%, which are less common types of publication, indicating a preference for more targeted and specific research articles rather than more general contributions like book chapters or editorials.

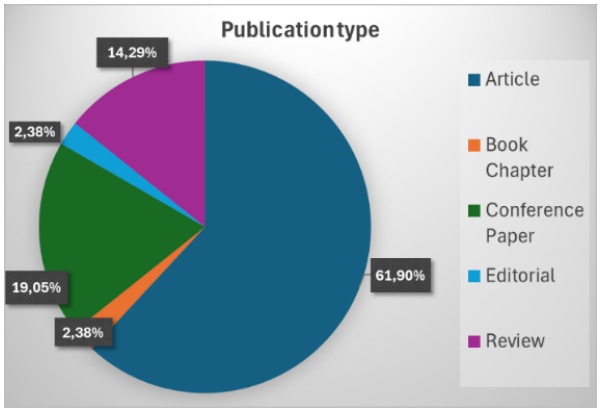

FIGURE 30: PUBLICATION TYPE OF PAPERS

As illustrated in the bar chart below (figure 31), the quantity of papers discussing the research question “How can the integration of digital technologies, such as IoT and artificial intelligence, improve resilience and risk management in the healthcare supply chain, while also reducing vulnerabilities and delays in product distribution?” is more than twice as high (37) as those addressing the research question “What are the main logistic, procurement and risk management challenges in the global healthcare supply chain during crises like the COVID-19 pandemic?” (18). This data highlights the strong interest of the academic community in the role of digital technologies in managing the healthcare supply chain, suggesting a research trend that focuses more on innovative solutions rather than merely analyzing existing challenges. The disparity in numbers may also indicate that logistical and managerial issues in crisis situations are less explored, pointing to a possible research gap in this area.

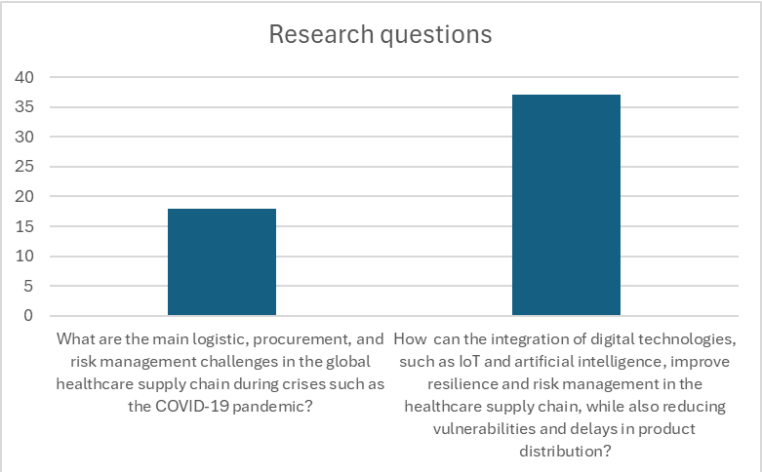

FIGURE 31: NUMBER OF PAPERS ADDRESSING THE RESEARCH QUESTIONS

LOGISTICS, PROCUREMENT AND RISK MANAGEMENT CHALLENGES IN HEALTHCARE SUPPLY CHAINS DURING CRISES

As shown in this bar chart (figure 32), COVID-19 is the crisis highlighted in the majority of papers examined, specifically in 15. This is probably due to the fact that, in 2020, the emergence of COVID disrupted the healthcare supply chain. In fact, COVID-19 has been the most impactful and discussed event in sectors related to global health, likely because of its unprecedented scale and the massive disruption of healthcare supply chains, thus confirming the importance of the pandemic in recent research. In contrast, health security and economic crises both appear in 6 articles, while biological crises appear in 5. This suggests that, in addition to the health crisis, economic concerns were also critical, possibly due to the global consequences of the pandemic. The biological crises, though less frequent, indicate that biological crises are still recognized, even if not always immediate or fully understood. Following closely, with an equal number of occurrences, are the geopolitical and technological crises with 4 articles. The similar number of articles on geopolitical and technological crises suggest that, even during a global health crisis, international politics and technological advancements (such as digital responses to the pandemic) were relevant themes. The two articles on natural crises likely indicate that, over the past few years, significant natural events have become less frequent, resulting in more attention being given to global crises like COVID-19, which had immediate and profound effects on the healthcare sector. Finally, the industrial crises with just one article, though indicating a lesser impact, may still have influenced public

health, considering the difficulties in the industrial sector and the production of healthcare goods.

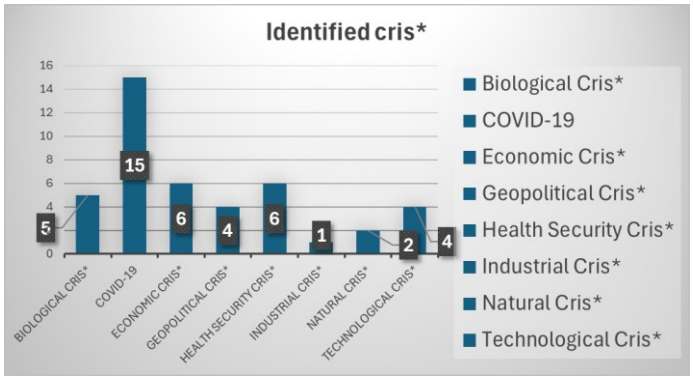

FIGURE 32: IDENTIFIED CRIS IN PAPERS*

In the following graph (figure 33), it can be observed that supply chain vulnerabilities are the main logistical challenge mentioned in 15 articles. This highlights how vulnerabilities in supply chains are recognized as the most critical issue, suggesting that many companies are focusing on addressing these vulnerabilities to ensure operational continuity. Following that, we have inventory management and visibility, cited in 14 articles. These topics are crucial in modern supply chains: visibility allows companies to better monitor the flow of products, while proper inventory management is essential to avoid shortages or excesses that could lead to delays or inefficiencies. Next, we find demand and supply management, discussed in 12 articles, followed by disruptions in transportation networks, mentioned in 9 articles. The difficulty in balancing demand and supply is another key aspect, especially in uncertain environments or during periods of high demand. This topic is discussed in a good number of articles, suggesting its relevance. Likewise, disruptions in transportation networks, which are a critical point in supply chains, can cause significant delays, reflecting the growing concern for logistics and transportation infrastructure. Finally, infrastructure and capacity limitations, quality assurance and scheduling are covered in 7 articles, while programming is discussed in 2 documents. These factors are essential to maintaining efficiency and quality in logistics operations. Infrastructure limitations can hinder supply chain growth, while quality and scheduling are crucial for ensuring smooth and seamless operations.

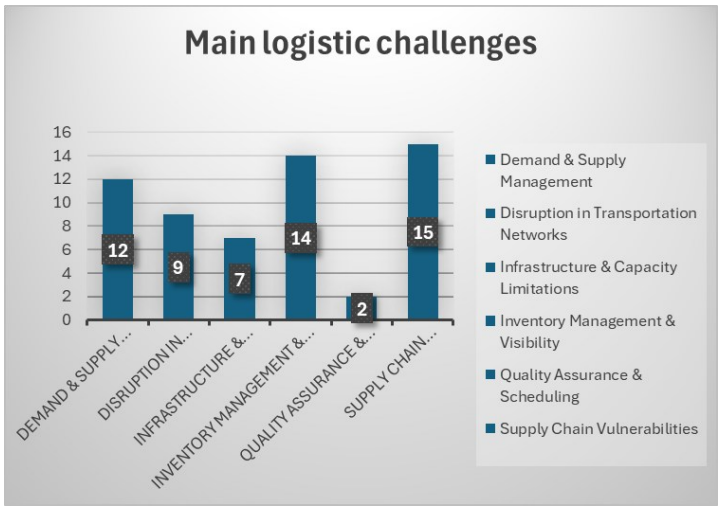

FIGURE 33: MAIN LOGISTIC CHALLENGES CITED IN PAPERS

In the bar chart below (figure 34), it is noticeable that, with 12 selected articles that mention them, the main procurement challenges are resource and material availability. This suggests that companies face concrete difficulties in ensuring that necessary resources are accessible and available in a timely manner, such as material shortages, disruptions in global supply chains or difficulty in finding reliable suppliers. Following this, with the same number of citations (10), are issues related to costs and economic feasibility, indicating that companies must make complex decisions about which resources to purchase based on budgets and the possibility of optimizing spending while maintaining competitiveness. Regulatory and compliance issues are also crucial challenges, suggesting that procurement management is significantly influenced by laws and regulations that vary internationally. Companies may encounter difficulties in complying with local and international regulations, especially in globalized contexts. Next, with 10 citations, there are challenges with suppliers, which remain a fundamental aspect, indicating the need for strong and reliable relationships with suppliers themselves. Problems in this area may include uncertainties in timing, difficulties in maintaining quality standards and logistical issues. Following this, with 6 citations, are data and communication challenges, which are important issues as transparency and clarity in communication with suppliers and across different company functions are essential for effective procurement. Problems in this area might indicate inefficiencies in the use of technology or the transmission of information. With 4 citations, issues related to demand and procurement strategies emerge, which are linked to the need to plan and forecast future needs

for optimal management of purchases. Finally, with 2 citations, there are concerns about ethics and sustainability, as well as quality and standardization. Although these are less frequently mentioned, they still indicate a growing commitment by companies to more responsible practices, although these are not always the immediate priorities in procurement.

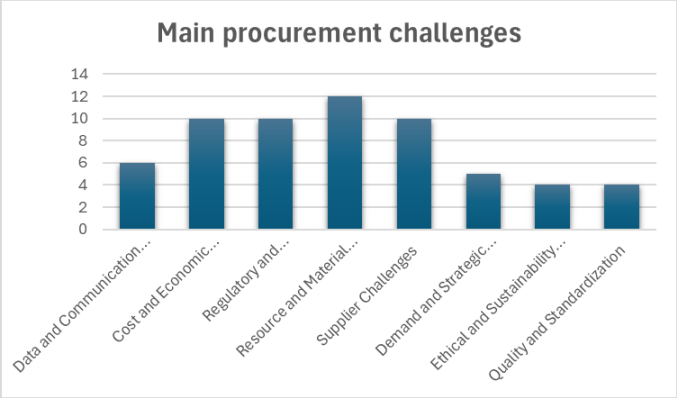

FIGURE 34: MAIN PROCUREMENT CHALLENGES CITED IN PAPERS

The figure (figure 35) shows that supply chain and logistics risks and crisis and urgent disruption management are the main risk management challenges mentioned in several articles, with 14 and 13 mentions, respectively, indicating that managing supply chain and crisis-related risks is a growing priority. These risks are heavily influenced by global issues such as the pandemic, geopolitical conflicts and natural disasters. Operational risks and digitalization are discussed in 10 articles, highlighting that, while highly relevant, they are less frequently addressed compared to supply chain and crisis-related risks, yet remain crucial to the evolution of risk management, especially in the context of growing digitalization. Financial and geopolitical risks and regulatory and policy challenges are discussed in 6 articles, suggesting that, although significant, these topics are treated from a more sector-specific or long-term perspective. Finally, real-time monitoring and mitigation and reputational and customer-centric risks appear in 3 articles, reflecting the increasing attention to real-time monitoring and reputation management, although they are considered less urgent topics. Health and safety risks are cited in 2 articles, a less prominent but still important topic, particularly in high-risk sectors such as industrial or healthcare industries.

FIGURE 35: MAIN RISK MANAGEMENT CHALLENGES CITED IN PAPERS

As shown in this bar chart (figure 36), apart from the return process, the various supply chain processes have roughly equal frequency of references. Specifically, delivery and storage are the most highlighted, each mentioned in 17 articles, while source appears in 16. Plan is mentioned in 15 documents, followed by enable with 13 and finally return with only 5. The distribution of mentions suggests that, although there is some uniformity, certain activities, such as delivery and storage, appear to be particularly crucial in supply chain management. This may reflect their practical centrality, especially in crisis contexts, where the physical management of resources and logistics are key to operational success. Alternatively, the reduced number of references concerning returns might suggest that this process is viewed as a lower priority in urgent circumstances, where procurement, distribution and storage operations are typically considered more urgent.

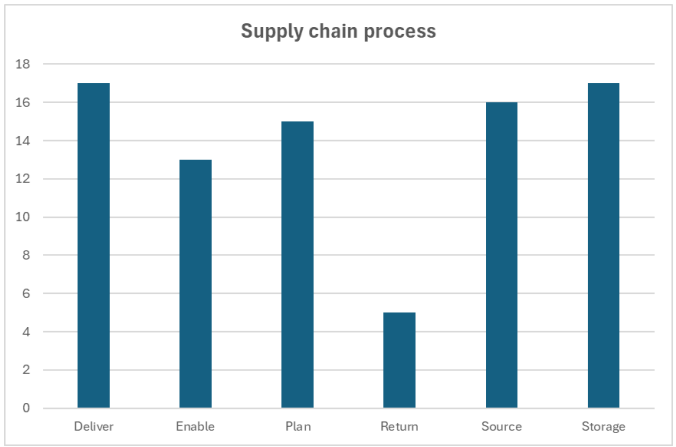

FIGURE 36: SUPPLY CHAIN PROCES DISCUSSED IN PAPERS

Observing the bar chart (figure 37), the most frequently mentioned product categories in the articles are pharmaceuticals with 15 citations, medical consumables with 13 and medical devices with 8. This implies that these categories are crucial in the healthcare supply chain, likely due to their importance in providing direct care to patients and are thus given higher importance in supply management strategies. On the other hand, In Vitro Diagnostics (IVD) are mentioned in 4 articles, hospital equipment in 3, laboratory supplies in 2 and sterilization and cleaning products in 1. The lower attention given to these categories may indicate that, while fundamental to hospital operations, they are considered secondary in crisis situations, posing a risk of operational issues if overlooked.

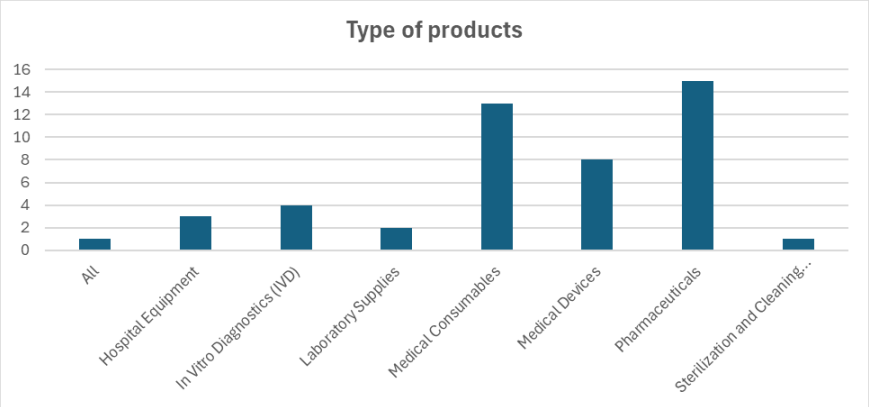

FIGURE 37: TYPE OF PRODUCTS MENTIONED IN PAPERS

DIGITAL TECHNOLOGIES FOR RESILIENCE AND RISK MANAGEMENT IN HEALTHCARE SUPPLY CHAINS

The graph (figure 38) shows that the most frequently mentioned products in the examined articles are pharmaceuticals, cited in 29 articles, followed by medical devices, mentioned in approximately 19 articles and medical consumables, appearing in 18 articles. This highlights the central role of pharmaceuticals and medical devices in the healthcare supply chain, given their critical importance in terms of availability, safety and regulatory compliance. In Vitro Diagnostics (IVD) are discussed in 10 articles, while hospital equipment appears in 8 articles and healthcare products in 4 articles. In contrast, less attention is given to categories like laboratory supplies (3 articles), products for the management of medical

waste and sterilization and cleaning products (both cited in 1 article). This disparity may reflect a greater research focus on elements perceived as more critical, even though all mentioned sectors are essential for the proper functioning and safety of the healthcare system.

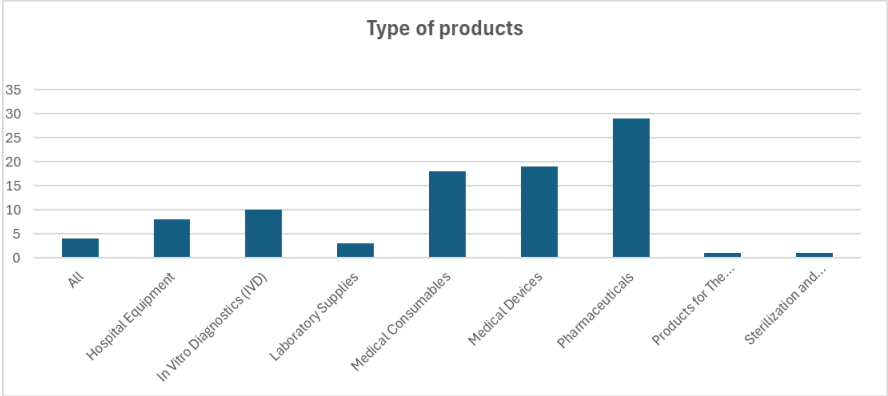

FIGURE 38: TYPE OF PRODUCTS MENTIONED IN PAPERS

In the bar chart shown below (figure 39), storage and deliver are both mentioned in 36 selected articles, suggesting that logistics and distribution are crucial aspects in healthcare supply chains, especially when it comes to risk management and resilience. The centrality of these processes indicates that efficiency in the physical management of materials and the timely distribution of products is seen as essential to ensure operational continuity and reduce the impact of potential disruptions. Following these, the supply process of the source appears in 33 documents and plan is mentioned in 31 articles. These results suggest that, although planning and procurement are also relevant to supply chain management, they are not perceived as priorities when focusing specifically on resilience and risk management. Rather, attention seems to be concentrated on processes that ensure the availability and distribution of goods. The term enables, mentioned in 24 articles, refers to digital technologies that enable supply chain processes, such as advanced monitoring systems, automation and predictive analytics. This suggests that, while these technologies are essential for improving resilience, they are not yet the main focus compared to operational and logistical aspects. Finally, return, the least mentioned process with 14 articles, appears less relevant in the context of resilience, likely because returns management is not seen as a priority for service continuity or immediate

risk management. Instead, return may be considered more of a logistics optimization aspect, with a less direct impact on the overall resilience of the supply chain.

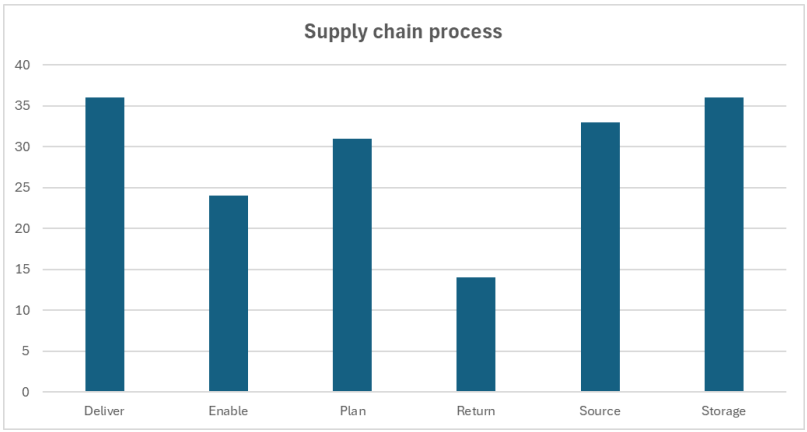

FIGURE 39: SUPPLY CHAIN PROCESS IN PAPERS

The analysis of this bar chart (figure 40) reveals that Internet of Things (IoT), Blockchain and Artificial Intelligence (AI) are among the most discussed technologies, with 30, 28, 27 and 26 mentions, respectively. This suggests a strong interest in their role within the supply chain, particularly in enhancing traceability, security and automation processes. Cloud Computing and Big Data & Analytics, both mentioned in 19 documents, highlight the importance of advanced data management and analysis to optimize decision-making and ensure an efficient flow of information. Cyber-Physical Systems (CPS), present in 10 articles, indicate a growing focus on integrating physical and digital systems. Emerging technologies such as Digital Simulation-Digital Twin (3 mentions) and 3D Printing (Additive Manufacturing) (1 mention) show that their impact on the supply chain is still evolving. These digital technologies are closely linked to resilience and risk management in healthcare supply chains, a field where digital transformation is essential for addressing uncertainties and operational disruptions. IoT and Blockchain enhance the traceability of healthcare products, ensuring transparency and security in the distribution of pharmaceuticals and medical devices. AI and Big Data & Analytics play a key role in predicting demand, managing inventory, and reacting to crucial occurrences, like pandemics or supply chain disruptions. Finally, the use of CPS and Digital Twin enables

scenario simulations to optimize logistics and production, increasing the supply chain's adaptability to emergency situations.

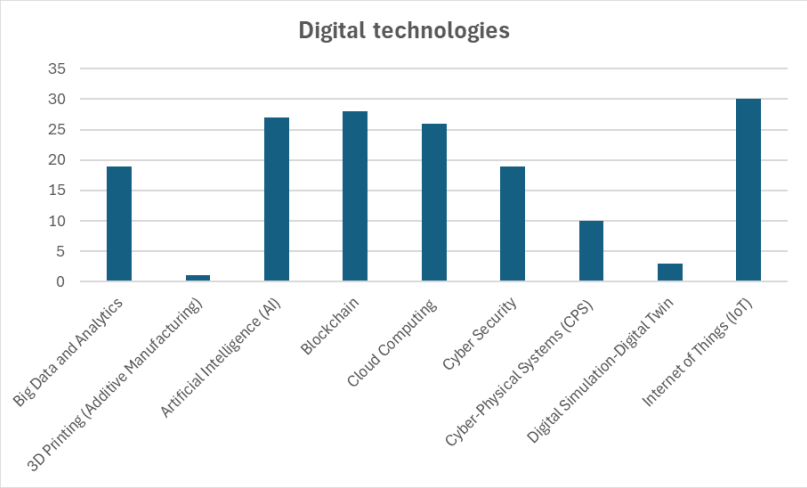

FIGURE 40: DIGITAL TECHNOLOGIES DISCUSSED BY PAPERS

Several resilience improvements are represented in the graph (figure 41), where it is evident that improved transparency and traceability are the most commonly mentioned, appearing in the largest number of articles, followed by optimization of logistics and operations with 24 citations and better inventory management and visibility with 23. The three least mentioned concepts are proactive monitoring and decision-making and enhanced data security, both cited in 14 articles and finally, building a resilient supply chain, with only one citation. These data suggest that transparency and traceability are considered the most fundamental aspects for improving the resilience of supply chains, likely because greater visibility allows for more effective identification and mitigation of risks. The optimization of logistics and operations, along with inventory management and visibility, emerge as equally important priorities, as they help reduce operational risks and ensure efficiency in daily operations. On the other hand, aspects such as proactive monitoring and data security seem to be less central, perhaps viewed as secondary priorities compared to more concrete measures aimed at optimizing operational flows. Finally, the low number of citations regarding the overall construction of a resilient supply chain might reflect a focus on specific solutions rather than a broader strategic approach, suggesting that, although

building overall resilience is crucial, many focus on individual tools or techniques to address immediate challenges

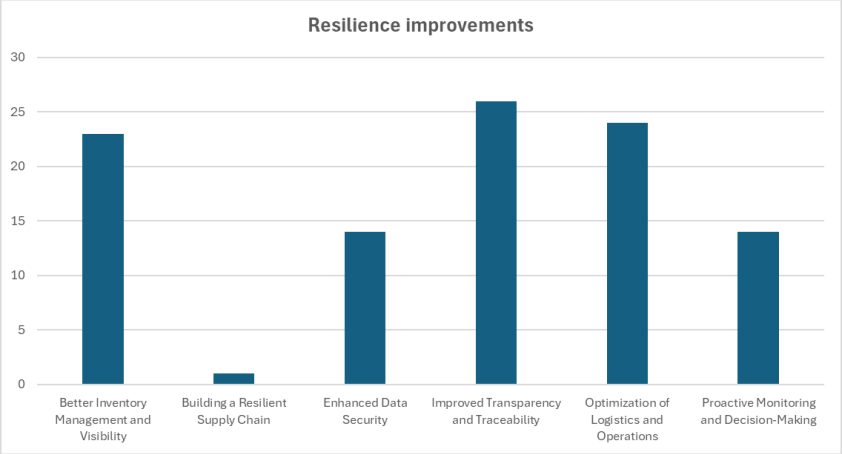

FIGURE 41: RESILIENCE IMPROVEMENTS MENTIONED BY PAPERS

From the following bar chart (figure 42), it can be noted that the predictive and proactive risk mitigation and enhanced data security and fraud prevention appear in a nearly equal number of examined articles, with 33 and 30 citations, respectively. This may suggest that these topics are especially significant in the context under study, suggesting a priority for businesses or researchers in addressing these specific aspects of risk. Both topics may reflect the growing emphasis on proactive data protection and fraud prevention, areas that are becoming increasingly important in a rapidly evolving technological world, with the rise of cybersecurity threats and the need for preventive solutions. On the other hand, the category risk management improvements appears with only 20 citations, a lower number in comparison to the other two topics. This could imply that overall enhancements in risk management practices are viewed as less critical or prioritized compared to more specialized solutions, such as predictive mitigation and data security. It could also reflect a trend towards focusing on more advanced and specific solutions, rather than general approaches or incremental improvements in risk management practices. Furthermore, the concentration of citations on predictive and proactive risk mitigation and enhanced data security and fraud prevention could indicate that companies are increasingly investing in innovative technologies and methodologies to address emerging risk challenges. The lesser focus on risk management improvement may be due to the fact that

this category is more focused on less advanced solutions or general improvements, which might not seem as urgent or specific as the other two areas.

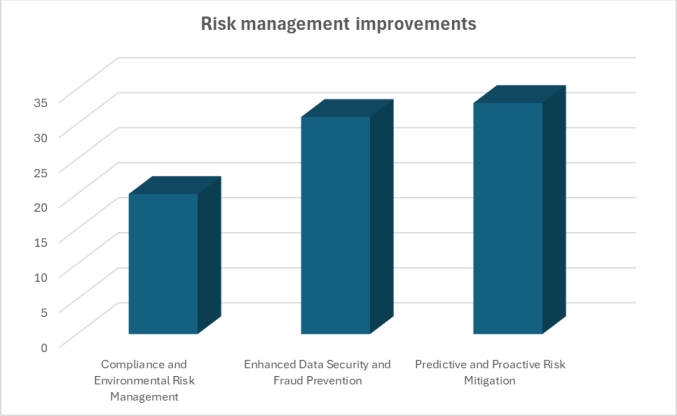

FIGURE 42: RISK MANAGEMENT IMPROVEMENTS CITED BY PAPERS

The defined actions to improve resilience (figure 43) that are most frequently cited are enhancing real-time monitoring and decision-making, with 33 mentions and leveraging digital technologies for resilience, with 31. This highlights a strong focus on adopting digital technologies and the ability to make rapid, data-driven decisions in real time. Following these are strengthening supply chain redundancy and flexibility (28 mentions), building collaborative and transparent ecosystems (26) and ensuring efficient resource allocation (25), confirming that, beyond digitalization, resilience also depends on supply chain flexibility, collaboration among system stakeholders and efficient resource management. Less attention appears to be given to ensuring inventory optimization and expanding access and building infrastructure, cited in 18 and 11 articles, respectively, which may indicate that these strategies are perceived as lower priorities compared to the previous ones. Even more marginal are ensuring logistics optimization and adopting patch management, with only 5 and 1 mentions. This could reflect an underestimation of the role of logistics in enhancing resilience or, alternatively, the perception that these actions are less critical than others. The data analysis thus suggests that resilience is primarily viewed as a matter of monitoring, digitalization and operational flexibility, while aspects such as logistics optimization and software update management seem to receive less attention in the discussion.

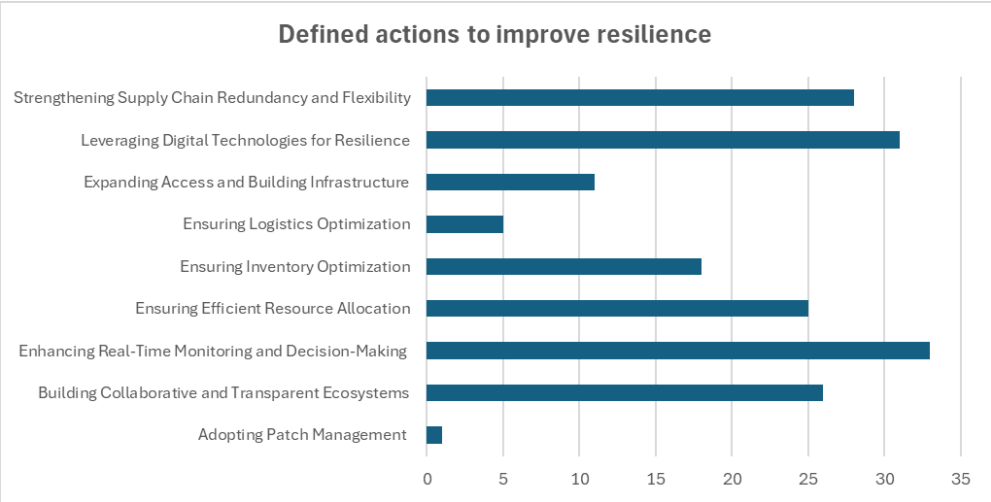

FIGURE 43: DEFINED ACTIONS TO IMPROVE RESILIENCE FOUND IN PAPERS

In the bar chart presented below (figure 44), it can be observed that the four most frequent actions to improve risk management in the selected articles—protecting sensitive data with encryption and security measures, strictly controlling access to data and prevent cyber-attacks, establishing regulatory compliance and strengthening data security and privacy—are discussed in a similar number of articles (27, 26, 23 and 22, respectively). This data highlights a clear priority given to security and regulatory compliance, suggesting that data protection and adherence to regulations are perceived as central elements in risk management. At a noticeable distance, developing predictive and risk mitigation models follows with 19 articles, building collaborative and transparent ecosystems with 16 and ensuring logistics optimization with 15. The numerical difference compared to the top four actions indicates that, while these strategies are considered relevant, they receive slightly less attention in the analyzed studies, possibly because they are associated with a more proactive approach or specific contexts. The least discussed actions—establishing metrics and standards, ensuring efficient resource allocation, developing and training the workforce, adopting secure coding practices and ensuring inventory optimization—appear in a significantly lower number of articles. Specifically, the first three are mentioned in 12, 10 and 9 articles, respectively, while the last two are cited in only 2. This suggests that topics such as defining metrics, resource allocation and workforce training receive less focus compared to security, likely because they are perceived as secondary or as requiring long-term interventions rather than immediate

measures. Similarly, the limited interest in secure software development and inventory optimization may reflect a perception of lower direct impact on risk management compared to other, more frequently cited strategies.

FIGURE 44: DEFINED ACTIONS TO IMPROVE RESILIENCE FOUND IN PAPERS

From the following graph (figure 45), it can be observed that Complexity of Implementation is the principal difficulty in the integration of digital technologies, with 37 citations in the analyzed articles. This suggests that companies and stakeholders face difficulties in implementation due to factors such as inadequate infrastructure, insufficient technical skills and complex business processes. Immediately after, costs, mentioned 32 times, emerge as another significant challenge. High initial investments, maintenance costs and the resources required for digital transformation can act as a deterrent for many organizations. Security concerns, present in 29 articles and privacy concerns, referenced in 28, emphasize the importance of data protection and cybersecurity in the adoption of digital technologies. This highlights the necessity for advanced solutions to safeguard sensitive information and counter cyber threats. Another significant factor is resistance to change, also mentioned in 28 articles. The difficulty in overcoming established habits and organizational inertia can hinder the transition to new technologies, making it essential to implement effective change management strategies. Regulatory constraints, with 26 citations, indicate that compliance with regulations represents a major barrier. Companies frequently need to adjust to intricate regulations, which may hinder the rapid adoption of new digital solutions. Finally, legal constraints appear in 17 articles, while policy

constraints are mentioned in 8. Although these factors have a lesser impact compared to others, compliance with laws and corporate policies remains a key consideration in the digitization process.

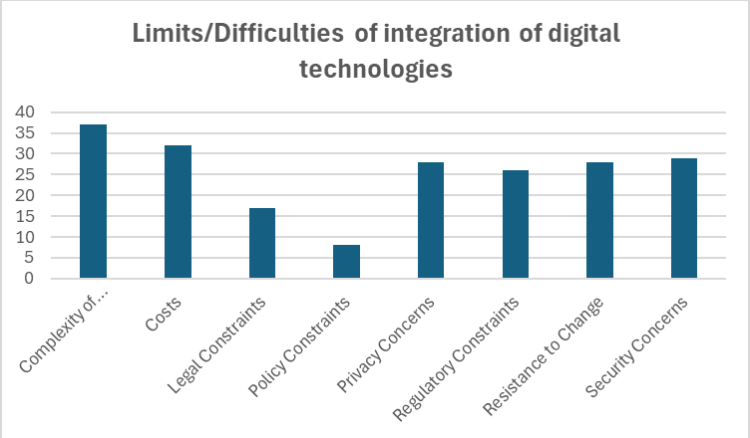

FIGURE 45: LIMITS/DIFFICULTIES OF INTEGRATION OF DIGITAL TECHNOLOGIES

2.6 RESULTS AND DISCUSSION

Based on the findings and the graph analysis performed in the previous section, several key aspects emerge regarding risk management and resilience within the healthcare supply chain. The increasing body of research in this field, particularly in recent years, suggests that the need to enhance supply chain resilience has become a central concern for both academia and industry. The rapid evolution of global crises, like the COVID-19 pandemic, has accelerated discussions on how to improve logistics, procurement and risk mitigation strategies. One of the most striking observations is the growing emphasis on digital technologies as a fundamental tool for strengthening supply chain resilience. Throughout the analyzed studies, technologies such as Blockchain, IoT and Artificial Intelligence (AI) appear as the most frequently discussed innovations, with many scholars highlighting their potential to improve supply chain transparency, traceability and responsiveness to disruptions. Blockchain, for instance, has been widely explored as a means to secure pharmaceutical supply chains, ensuring that critical medications and medical supplies reach their intended destinations without risks of counterfeiting or fraud. Similarly, IoT-based solutions offer real-time monitoring of logistics, allowing organizations to track the movement of goods and anticipate potential bottlenecks before they escalate into major disruptions. However, despite the clear advantages of these technologies, their

implementation remains uneven across the industry. Large healthcare organizations, often backed by substantial financial and technological resources, are more capable of adopting these innovations, while small and medium-sized healthcare providers struggle with integration due to cost constraints and limited technical expertise. This divide suggests that future advancements should focus on developing cost-effective solutions that facilitate the adoption of digital tools at different levels of the healthcare supply chain. Moreover, regulatory challenges continue to slow down the implementation of advanced digital systems. Strict compliance requirements, particularly in cross-border healthcare supply chains, pose significant barriers to the widespread use of AI-driven decision-making and automated tracking systems. In addition to technological advancements, another key trend emerging from the research is the increasing role of developing countries in shaping the discourse on healthcare supply chain resilience. A significant portion of recent studies comes from regions such as India and Iran, indicating that nations facing greater structural challenges are actively seeking innovative ways to improve supply chain efficiency. This shift in research contributions reflects a broader effort to localize supply chain solutions, moving away from an overreliance on global supply networks that have proven vulnerable to geopolitical and economic fluctuations. While countries with established healthcare infrastructures continue to refine existing models, emerging economies appear to be at the forefront of experimenting with new strategies, hybrid logistics models and region-specific technological adaptations. Another critical issue frequently discussed in the literature is the vulnerability of the healthcare supply chain, particularly in times of crisis. The COVID-19 pandemic underscored how supply chains can become highly fragile due to transportation disruptions, supplier shutdowns and unpredictable fluctuations in demand. Many healthcare organizations found themselves unable to respond effectively to shortages of essential medical products, exposing significant gaps in inventory management and emergency stockpiling strategies. The studies analyzed suggest that companies and institutions should prioritize diversified sourcing strategies, improved demand forecasting and the development of emergency logistics protocols to prevent similar breakdowns going forward. Moreover, the differentiation between risk mitigation and resilience development strategies is becoming increasingly relevant in current discussions. While risk management

focuses on responding to threats as they arise, resilience-building emphasizes the creation of long-term frameworks to withstand future disruptions. Interestingly, despite the growing attention to resilience, the concept remains underexplored in comparison to traditional risk management approaches. Many studies focus on short-term mitigation strategies rather than proactive resilience planning, highlighting the need for more research into standardized resilience assessment tools and adaptive supply chain models. Another important theme emerging from the analysis is the role of supplier selection and integration in determining overall supply chain robustness. Several studies argue that supply chain efficiency can be significantly improved by fostering closer relationships between healthcare providers and their suppliers. In particular, vertically integrated supplier models—where suppliers and distributors work in close coordination—seem to offer greater flexibility in responding to demand shifts and supply shortages. At the same time, geographical diversification of suppliers is seen as a crucial factor in reducing dependency on specific regions, particularly in light of recent global trade disruptions. Finally, the regulatory landscape surrounding healthcare supply chains continues to play a decisive role in shaping operational strategies. The increasing complexity of compliance requirements, data protection laws and pharmaceutical distribution regulations means that healthcare supply chains must operate within strict legal frameworks, often limiting the speed at which new technological solutions can be adopted. Studies suggest that greater international cooperation and policy alignment could facilitate smoother healthcare logistics operations, allowing organizations to implement innovative risk management strategies without excessive bureaucratic hurdles. Overall, these findings point to a fundamental shift in the way healthcare supply chains are being conceptualized, moving from reactive risk mitigation to proactive resilience planning. Nonetheless, various challenges remain to be tackled to close the gap between theoretical research and practical implementation. Moving forward upcoming research and industry initiatives should focus on:

- Developing AI-driven predictive models that can anticipate disruptions before they occur, allowing for more agile and responsive supply chain management.

- Creating standardized resilience metrics to assess how well healthcare supply chains are prepared for future crises.
- Enhancing collaboration between public and private sectors to ensure that supply chain innovations are accessible to all stakeholders, regardless of financial constraints.
- Streamlining regulatory frameworks to facilitate implementation of digital solutions while maintaining security and compliance standards.

By addressing these key areas, healthcare supply chains can evolve into more resilient and adaptive networks, capable of sustaining operations even in the face of global disruptions.

3 CONCLUSIONS AND PERSPECTIVES

Following a meticulous and in-depth examination of the collected data, this study provides a comprehensive understanding of the key challenges influencing the supply chain in healthcare, with a particular focus on digital transformation, operational resilience and sustainability. The findings discussed throughout this research highlight the critical role of emerging technologies in optimizing supply chain management, emphasizing the importance of adopting strategic approaches tailored to different geographical and economic contexts. Additionally, the study explores how innovative digital tools enhance transparency and efficiency, addresses existing limitations and outlines potential future research directions to support continuous improvement in healthcare logistics.

3.1 BENEFITS OF THE WORK

This research significantly contributes to understanding and improving the healthcare supply chain, emphasizing its practical implications for companies, healthcare institutions and policymakers. Blockchain technology enhances transparency in procurement processes, reducing risks associated with counterfeit products. For example, during the COVID-19 pandemic, pharmaceutical companies used blockchain to track the origin and authenticity of vaccines, ensuring compliance with international safety standards (Ahmad et al., 2023). Another example is Boston Scientific, which implemented a blockchain-based solution to automate inventory management and improve collaboration with clinics, reducing order-to-fulfillment time from nearly a week to an average of 36 hours [31]. AI-powered inventory management systems have also been adopted to optimize stock levels, minimizing waste and preventing shortages during crises [32]. Companies such as 10mg have developed AI platforms that facilitate loans to healthcare suppliers in emerging markets, improving access to essential resources [33]. IoT solutions enable real-time monitoring of critical resources, like temperature-sensitive medications and vaccines. Hospitals equipped with IoT-based temperature sensors ensured the safe storage and transportation of

vaccines during the pandemic, maintaining their efficacy and availability [34]. Hospitals like Guy's and St Thomas' have used robots for surgical procedures and supply deliveries, increasing operational efficiency and reducing delays [35]. Additionally, the NAIBHSC initiative integrates IoT with blockchain to track medical products, preventing counterfeits and enhancing transparency (Nanda et al., 2023). Centralized digital platforms provide real-time data on supply chain dynamics, enabling efficient resource allocation during emergencies. Germany's decentralized healthcare supply chain model allowed regional facilities to adapt quickly to local needs, ensuring flexibility and resilience in resource distribution [36]. Singapore's centralized logistics system, managed by ALPS Healthcare, streamlined nationwide operations through advanced inventory control and demand forecasting, ensuring timely delivery of medical supplies [37]. In Ireland, the Health Service Executive (HSE) has published a Climate Action Strategy to achieve net-zero emissions by 2050, highlighting the importance of sustainable resource management in healthcare [38]. Finally, sustainability is a key focus of this research. Healthcare providers increasingly adopt eco-friendly practices, such as using recyclable packaging and optimizing transportation routes to reduce emissions. Digital tools like AI and IoT support these initiatives by automating resource tracking and minimizing waste, promoting responsible logistics [39].

3.2 LIMITATIONS

While this research provides valuable insights, certain limitations must be acknowledged. The role of advanced technologies and their potential limitations merit particular attention. The study extensively discusses the impact of Artificial Intelligence, Blockchain and the Internet of Things on healthcare supply chain management. However, the exclusion of other innovative solutions, like Digital Twin technology, limits the exploration of opportunities for future digitalization in this sector. At the same time, external technological factors could further influence the applicability of these solutions. For instance, the adoption of 5G could revolutionize real-time tracking, while quantum computing might bring advancements in optimization algorithms. On the other hand, these technologies also come with scalability and cost-related challenges that deserve attention. The study is also

subject to methodological constraints and biases, which warrant deeper analysis. For example, the application of specific search queries to identify relevant publications may have excluded studies using alternative terminology or differing indexing standards, thus narrowing the scope of the analysis. Similarly, the focus on predominantly English-language sources might have left out valuable contributions from non-English-speaking regions, further impacting the comprehensiveness of the study. Furthermore, external variables such as economic and regulatory factors may significantly affect the findings. Economic conditions, including resource availability and healthcare funding levels, could influence the adoption of advanced technologies in healthcare supply chains. Regulatory frameworks, varying across regions, shape the feasibility of implementing proposed solutions, with compliance requirements that may delay or complicate their application. The geographical distribution of the analyzed studies represents another limitation. Most contributions come from countries like India, the United Kingdom and the United States, with fewer insights from African and South American contexts. This imbalance might affect the global applicability of the findings, making it harder to draw universally relevant conclusions. Lastly, while optimization and simulation models for healthcare supply chains were explored, their lack of practical validation in real-world scenarios remains a significant limitation. This restricts the immediate applicability of the recommendations and emphasizes the need for further empirical testing.

3.3 FUTURE RESEARCH

To ensure continuous progress in the digitalization and optimization of the healthcare supply chain, further research should focus on addressing the limitations identified in this study. The following directions are proposed to guide future investigations:

- Localized analysis of geographical challenges: while this study adopts a global perspective, targeted research on specific regions could uncover unique local challenges and tailor solutions to enhance supply chain resilience. For instance, investigating healthcare logistics in low-resource

settings or regions with regulatory constraints could provide insights into overcoming barriers specific to these environments.

- Adoption of digital technologies by key players: research could explore how major healthcare organizations, such as pharmaceutical companies and hospitals, are implementing advanced tools. Comparative case studies across organizations or regions could shed light on successful strategies and barriers to large-scale adoption. This approach would help in developing frameworks that can be scaled effectively.
- Cross-Sectoral studies: conducting comparative studies between healthcare and other critical industries, such as automotive or food, could yield transferable methodologies for optimizing healthcare logistics. For example, assessing the integration of just-in-time delivery models in retail or manufacturing could offer innovative approaches to inventory management in hospitals.
- Validation of theoretical models: practical testing of the theoretical optimization and simulation models discussed in this study is essential to bridge the gap between theory and practice. Pilot studies or real-world applications within hospitals, pharmaceutical companies and service providers can validate hypotheses and provide actionable recommendations tailored to operational constraints.
- Exploration of emerging technologies: The potential of technologies not covered extensively in the current study should be explored.

  For instance:

  - Digital Twin technology can enable accurate demand forecasting, improve inventory management, and optimize process simulations.
  - Augmented Reality (AR) could enhance warehouse management and workforce training.
  - Green technologies like sustainable packaging and energy-efficient transportation solutions could align healthcare supply chains with sustainability goals, while also addressing cost-efficiency.

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APPENDIX

Paper n.	Title of the article	Author(s)	Publication date	Name of journal/conference, volume, issue, book, page numbers	Publication type	Country of affiliation of the first author	N. citations (Scopus)	Author Keywords	Methodology	Methodology type	Scopus Link	Identified cris*	Main logistic challenges	Main procurement challenges	Main risk management challenges	Supply chain process	Type of products	Type of products.	Supply chain process.	Digital technologies	Resilience improvements	Risk management improvements	Defined actions to improve resilience	Defined actions to improve risk management	Limits/Difficulties of integration of digital technologies
1	Supply Chains Problem During Crises: A Data-Driven Approach	Salamian, Farima	2024	Modelling; Volume 5; Issue 4; Pages 2001 - 2039	Article	Iran	0	grasshopper optimization algorithm (GOA)	Mathematical Model Development	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85213439241&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=cl&cluster=scolang%2C%22English%22%2Ct&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22supply+Chain%22+AND+%22cris*%22%29&sessionSearchId=918d15426edeef376dee7b8ecb9b2485&relpos=11	Health Security Cris*	Disruption in Transportation Networks	Supplier Challenges (Supply Chain Stability and Resource & Material Availability Issues)	Regulatory and Policy Challenges	Plan	Pharmaceuticals								
1		et al						GRU neural network	Optimization Model Development			Biological Cris*	Supply Chain Vulnerabilities (Distribution and Transport Bottlenecks, Fluctuations in Demand, Supply chain Instability, Inefficient vaccine procurement processes)	Resource and Material Availability	Supply Chain and Logistics Risks (Transportation and Distribution Disruptions, Storage and Inventory Management Issues, Demand and Supply Uncertainties, Operational and Coordination Challenges)	Source									
1								mixed-integer linear programming (MILP)	Prediction Model			Economic Cris*	Demand & Supply Management (Supply and Demand Issues, Healthcare Priorities and Strategies, Supply Chain Efficiency)	Regulatory and Compliance Issues (Transportation and Distribution Regulations, Regulatory and Compliance Issues)	Real-Time Monitoring and Mitigation	Storage									
1								pharmaceutical supply chain	Simulation Model Development			Geopolitical Cris*	Infrastructure & Capacity Limitations (Resource and Material Availability)	Cost and Economic Feasibility (Supply Chain Costs)	Operational Risks and Digitalization (Digitalized Supply Chain and Performance Challenges, System and Technology Integration Risks)	Deliver									
1								ε-constraint method	Empirical Research				Inventory Management & Visibility (Demand and Inventory Management Challenges, Data and Tracking Challenges)	Demand and Strategic Procurement Issues (Fluctuating Demand & Unpredictability, Inefficiencies in Supplier & Logistics Coordinations, Procurement & Supply Balancing Challenges)	Crisis and Urgent Disruption Management	Return									
1									Case Study							Enable									
1									Literature Review																
1									Mixed-Integer Linear Programming (MILP)																
1									Multi-Objective Optimization																
2	Evaluation of COVID-19 mortality using machine learning regression methods based on health system indicators	Bulut, Canan	2024	Sigma Journal of Engineering and Natural Sciences; Volume 42; Issue 6; Pages 1797 - 1805	Article	Turkey	0	COVID-19	Literature Review	Quantitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85211461532&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=cl&cluster=scolang%2C%22English%22%2Ct&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22supply+Chain%22+AND+%22cris*%22%29&sessionSearchId=918d15426edeef376dee7b8ecb9b2485&relpos=12	COVID-19	Supply Chain Vulnerabilities (Fluctuations in demand, Distribution and Transport Bottlenecks, Production-related challenges)	Supplier Challenges (Resource & Material Availability Issues)	Data Security and Privacy Risks	Plan	All								
2		et al						Health Indicator	Empirical Research				Infrastructure & Capacity Limitations (Resource and Material Availability)	Resource and Material Availability	Regulatory and Policy Challenges	Source									
2								Machine Learning	Prediction Model				Inventory Management & Visibility (Demand and Inventory Management Challenges, Data and Tracking Challenges)	Cost and Economic Feasibility (Supply Chain Costs)	Crisis and Urgent Disruption Management	Storage									
2								Prediction	Empirical Model Study						Financial and Geopolitical Risks (Financial Risks, Geopolitical Risks)	Deliver									
2									Comparative Analyses							Enable									
3	Impact of COVID-19 on the neglected tropical diseases: a scoping review	Butala, Caitlin Brigid	2024	Infectious Diseases of Poverty; Volume 13; Issue 1; Article number 55	Review	United Kingdom	2	COVID-19	Systematic Literature Review (SLR)	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85200001988&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=cl&cluster=scolang%2C%22English%22%2Ct&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22supply+Chain%22+AND+%22cris*%22%29&sessionSearchId=918d15426edeef376dee7b8ecb9b2485&relpos=14	Economic Cris*	Supply Chain Vulnerabilities (Production-related challenges, Supply Shortages and Unpredictability, Waste and Inefficiency in resource management, Supply Chain Instability)	Supplier Challenges (Financial & Investment Challenges, Supply Chain Stability and Resilience Issues,Resource & Material Availability Issues)	Supply Chain and Logistics Risks (Storage and Inventory Management Issues, Transportation and Distribution Disruptions)	Plan	Pharmaceuticals								
3		et al						Disability adjusted life years	Bibliometric Analysis			Health Security Cris*	Demand & Supply Management (Healthcare Priorities and Strategies, Supply and Demand Issues, Supply Shortages/Disruptions)	Resource and Material Availability	Financial and Geopolitical Risks (Geopolitical Risks)	Source	Medical Devices								
3								Funding				COVID-19		Cost and Economic Feasibility (Supply Chain Costs, Production and Procurement Costs)	Crisis and Urgent Disruption Management	Storage	Medical Consumables								
3								Investment						Demand and Strategic Procurement Issues (Distribution & Resource Allocation Issues, Inefficiencies in Supplier & Logistics Coordination, Distribution & Resource Allocation Issues)		Deliver	In Vitro Diagnostics (IVD)								
3								Millennium development goals								Return	Laboratory Supplies								
3								Neglected tropical diseases								Enable									
3								Research and development																	
3								Sustainable development goals																	
3								WHO																	
4	A robust optimization model for multi-objective blood supply chain network considering Scenario Analysis under uncertainty: a multi-objective approach	Fariman, Saeed Khakshouri	2024	Scientific Reports; Volume 14; Issue 1; Article number 9452	Article	Iran	3	Blood supply chain	Literature Review	Quantitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85191300088&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=cl&cluster=scolang%2C%22English%22%2Ct&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22supply+Chain%22+AND+%22cris*%22%29&sessionSearchId=918d15426edeef376dee7b8ecb9b2485&relpos=15	Natural Cris*	Disruption in Transportation Networks	Supplier Challenges (Resource & Material Availability Issues)	Operational Risks and Digitalization (Digitalized Supply Chain and Performance Challenges, IT and Network Disruptions)	Plan	Medical Consumables								
4		et al						Disaster	Mathematical Model Development			Health Security Cris*	Supply Chain Vulnerabilities (Waste and Inefficiency in resource management, Storage and Infrastructure limitations, Supply chain Instability)	Resource and Material Availability	Supply Chain and Logistics Risks (Demand and Supply Uncertainties,Operational and Coordination Challenges)	Source									
4								HealthCare	Optimization Model Development			COVID-19	Demand & Supply Management (Supply and Demand Issues, Supply Shortages/Disruptions)	Cost and Economic Feasibility (Transportation and Distribution Costs, Supply Chain Costs)	Crisis and Urgent Disruption Management	Storage									
4								Robustness	Scenario Analysis				Infrastructure & Capacity Limitations (Resource and Material Availability)	Demand and Strategic Procurement Issues (Fluctuating Demand & Unpredictability,Procurement & Supply Balancing Challenges, Distribution & Resource Allocation Issues)	Financial and Geopolitical Risks (Financial Risks)	Deliver									
4									Case Study				Inventory Management & Visibility (Logistics and Coordination Challenges, Demand and Inventory Management Challenges, Logistics and Coordination Challenges)	Data and Communication Challenges		Enable									
5	Lessons from the COVID-19 Pandemic: Promoting Vaccination and Public Health Resilience, a Narrative Review	Pennisi, Flavia	2024	Vaccines; Volume 12; Issue 8; Article number 891	Review	Italy	4	COVID-19 pandemic	Literature Review	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85202446932&origin=resultslist&sort=plf-f&src=s&sid=6f63b932a2c32dc2c6df6c1264d2d579&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22supply+Chain%22+AND+%22COVID-19%22%29&sl=61&sessionSearchId=6f63b932a2c32dc2c6df6c1264d2d579&relpos=19	COVID-19	Demand & Supply Management (Healthcare Priorities and Strategiesy, Supply Shortages/Disruptions, Supply Chain Efficiency)	Resource and Material Availability	Supply Chain and Logistics Risks (Transportation and Distribution Disruptions, Operational and Coordination Challenges, Demand and Supply Uncertainties)	Source	Pharmaceuticals								
5		et al						public health strategy					Inventory Management & Visibility (Logistics and Coordination Challenges)	Ethical and Sustainability Concerns (Inequality in Healthcare and Access)	Reputational and Customer-Centric Risks (Reputation Impact Risks, Customer Experience and Reliability Risks)	Deliver									
5								vaccine hesitancy					Supply Chain Vulnerabilities (Infrastructure Weaknesses, Inefficient vaccine procurement processes)	Cost and Economic Feasibility (Specific Supply Chain Costs)	Operational Risks and Digitalization (Cybersecurity and Data Risks)	Enable									
6	Modelling supply chain Visibility, digital Technologies, environmental dynamism and healthcare supply chain Resilience: An organisation information processing theory perspective	Tiwari, Manisha	2024	Transportation Research Part E: Logistics and Transportation Review; Volume 188; Article number 103613	Article	United Kingdom	4	Digital Technologies	Literature Review	Quantitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85196042944&origin=resultslist&sort=plf-f&src=s&sid=53692f98fc2f72c21a04013123266c7&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22supply+chain%22+AND+%22digital+technolog*%22AND+%22resilience%22%29&sl=88&sessionSearchId=53692f98fc2f72c21a04013123266c7&relpos=1	COVID-19	Disruption in Transportation Networks	Supplier Challenges (Supply Chain Stability and Resilience Issues,Operational & Technological Challenges)	Data Security and Privacy Risks	Storage	Medical Consumables	Medical Consumables	Storage	Artificial Intelligence (AI)	Improved Transparency and Traceability (of Medical Supplies, Pharmaceuticals, Medical Equipment)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Strengthening Communication and Digital Collaboration, Enhancing Monitoring and Optimization)	Building Collaborative and Transparent Ecosystems (Supply Chain and Healthcare Ecosystems)	Complexity of Implementation
6		et al.						Environmental Dynamism	Survey			Health Security Cris*	Supply Chain Vulnerabilities (Fluctuations in Demand, Supply Shortages and Unpredictability)	Resource and Material Availability	Regulatory and Policy Challenges	Deliver	Pharmaceuticals	Pharmaceuticals	Deliver	Big Data and Analytics	Proactive Monitoring and Decision-Making (Supply Chain & Inventory Tracking; Logistics & Inventory Optimization, Supply Chain Resilience & Risk Management)		Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Inventory Management & Buffer Stocks, Logistics & Distribution Flexibility, Real-Time Data & Monitoring)	Developing and Training the Workforce	Regulatory Constraints
6								Healthcare Supply Chain Resilience	Structural Equation Modeling (SEM)			Economic Cris*	Inventory Management & Visibility (Data and Tracking Challenges)	Regulatory and Compliance Issues (Data and Communication Challenges, Regulatory and Compliance Issues)	Operational Risks and Digitalization (Cybersecurity and Data Risks, System and Technology Integration Risks)	Plan			Plan	Cyber-Physical Systems (CPS)			Ensuring Efficient Resource Allocation (of Medical Supplies, Pharmaceuticals, Healthcare Equipment and Infrastructure, Inventory and Logistics Resources)	Ensuring Logistics Optimization (Supply Chain and Demand Management, Distribution)	
6								Information Processing Theory	Conceptual Framework					Ethical and Sustainability Concerns (Transparency and Fair Practices, Inequality in Healthcare and Access, Environmental Sustainability)	Supply Chain and Logistics Risks (Demand and Supply Uncertainties, Transportation and Distribution Disruptions, Operational and Coordination Challenges)					Internet of Things (IoT)				Ensuring Efficient Resource Allocation (of Medical Supplies, Pharmaceuticals, Healthcare Equipment and Infrastructure, Inventory and Logistics Resources)	
6								SDG 3: Good health and well-being	Empirical Research					Cost and Economic Feasibility (Digital and Technological Infrastructure Costs, Supply Chain Costs, Production and Procurement Costs)	Financial and Geopolitical Risks (Geopolitical Risks, Financial Risks)					Cloud Computing					
6								Supply Chain Visibility							Crisis and Urgent Disruption Management										

Paper n.	Title of the article	Author(s)	Publication date	Name of journal/conference, volume, issue, book, page numbers	Publication type	Country of affiliation of the first author	N. citations (Scopus)	Author Keywords	Methodology	Methodology type	Scopus Link	Identified cris*	Main logistic challenges	Main procurement challenges	Main risk management challenges	Supply chain process	Type of products	Type of products.	Supply chain process.	Digital technologies	Resilience improvements	Risk management improvements	Defined actions to improve resilience	Defined actions to improve risk management	Limits/Difficulties of integration of digital technologies
7	A Systematic Review on the Use of AI-Powered Cloud Computing for Healthcare Resilience	Maguraushe, Kudakwashe	2024	Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST; Volume 520; Pages 126 - 141	Conference Paper	South Africa	0	artificial intelligence	Systematic Literature Review (SLR) -	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85198596637&origin=resultslist&sort=plf-f&src=s&sid=6f63b932a2c32dc2c6df6c1264d2d579&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+digital+technolog*%22+AND+%22resilience%22%29&sl=61&sessionSearchId=6f63b932a2c32dc2c6df6c1264d2d579&relpos=6							Pharmaceuticals	Enable	Artificial Intelligence (AI)	Proactive Monitoring and Decision-Making (Patient & Resource Monitoring, Supply Chain & Inventory Tracking; Healthcare & Emergency Response Strategies)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Implementing Digital Technologies and Automation)	Developing and Training the Workforce	Policy Constraints
7		et al						cloud-based	Survey									Medical Devices	Plan	Cloud Computing	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Enhanced Data Security and Fraud Prevention	Ensuring Efficient Resource Allocation (Medical Supplies, Human Resources, Digital and Technological Resources)	Establishing Metrics and Standards (Performance and Efficiency Metrics; Data Integrity, Security, and Privacy Standards) .	Privacy Concerns
7								healthcare resilience										In Vitro Diagnostics (IVD)	Source	Internet of Things (IoT)				Protecting Sensitive Data with Encryption and Security Measures (Patient and Medical Records, Supply Chain and Transaction Data, Security and Privacy Measures)	Complexity of Implementation
7								systematic review											Deliver	Big Data and Analytics				Ensuring Logistics Optimization (Supply Chain and Demand Management, Distribution)	Resistance to Change
7																								Ensuring Efficient Resource Allocation (Medical Supplies, Human Resources, Digital and Technological Resources)	Legal Constraints
7																									Regulatory Constraints
8	Analyzing barriers and strategies in digital transformation for resilient SC in healthcare using AHP and MABAC under uncertain environment	Seker, Sukran	2024	Journal of Enterprise Information Management	Article	Qatar	0	DT	Systematic Literature Review (SLR) -	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85201128120&origin=resultslist&sort=plf-f&src=s&sid=fa1932a4b3fff2a1e57a00b72034dbb&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+digital+technolog*%22+AND+%22risk%22%29&sl=84&sessionSearchId=fa1932a4b3fff2a1e57a00b72034dbb&relpos=11	COVID-19	Disruptions in Transportation Networks	Supplier Challenges (Operational & Technological Challenges)	Data Security and Privacy Risks	Source	Medical Devices	Medical Devices	Source	Internet of Things (IoT)	Improved Transparency and Traceability (of Supply Chain Operations and Processes, Movement and Tracking) .	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration, Enhancing Monitoring and Optimization, Implementing Digital Technologies and Automation)	Developing and Training the Workforce	Privacy Concerns
8		et al						Healthcare	Multi-Criteria Decision-Making Model (MCDM)			Economic Cris*	Demand & Supply Management (Uncertain Demand, Supply Shortages/Disruptions, Coordination and Logistics, Regulatory and Compliance)	Resource and Material Availability	Regulatory and Policy Challenges	Deliver	Pharmaceuticals	Pharmaceuticals	Deliver	Blockchain	Proactive Monitoring and Decision-Making (Supply Chain & Inventory Tracking, Patient & Resource Monitoring, Supply Chain Resilience & Risk Management)	Enhanced Data Security and Fraud Prevention	Ensuring Efficient Resource Allocation (Human Resources, Medical Supplies, Financial Resources)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Costs (Initial Investment Costs)
8								MCDM	Survey			Geopolitical Cris*	Infrastructure & Capacity Limitations (Data and Communication Challenges, Resource and Material Availability)		Operational Risks and Digitalization (Cybersecurity and Data Risks, Compliance and Regulatory Risks, Operational and Logistical Risks)	Return	Hospital Equipment	Hospital Equipment	Return	Cloud Computing			Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Inventory Management & Buffer Stocks)	Establishing Metrics and Standards (Performance and Efficiency Metrics)	Resistance to Change
8								Resilience							Risks Related to Health and Safety	Storage	Medical Consumables	Medical Consumables	Storage	Cyber Security			Enhancing Real-Time Monitoring and Decision-Making	Ensuring Logistics Optimization (Transportation, Warehousing, Last-Mile Delivery)	Complexity of Implementation
8								Supply chain												Artificial Intelligence (AI)			Ensuring Logistics Optimization (Transportation, Warehousing, Last-Mile Delivery)	Ensuring Efficient Resource Allocation (Human Resources, Medical Supplies, Financial Resources)	Security Concerns
9	Resilience capabilities of healthcare supply chain and supportive digital technologies	Furstenau, Leonardo Bertolin	2022	Technology in Society; Volume 71; Article number 102095	Article	United Kingdom	33	Healthcare digitalization	Literature Review	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85137164073&origin=resultslist&sort=plf-f&src=s&sid=6f63b932a2c32dc2c6df6c1264d2d579&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+digital+technolog*%22+AND+%22resilience%22%29&sl=61&sessionSearchId=6f63b932a2c32dc2c6df6c1264d2d579&relpos=9							All	Plan	Big Data and Analytics	Proactive Monitoring and Decision-Making (Supply Chain & Inventory Tracking; Logistics & Inventory Optimization)	Predictive and Proactive Risk Mitigation	Ensuring Efficient Resource Allocation (Medical Supplies, Healthcare Equipment and Infrastructure)	Protecting Sensitive Data with Encryption and Security Measures (Patient and Medical Records, Health-Related Data, Personal and Sensitive Information)	Complexity of Implementation
9		et al						Healthcare supply chain	Semi-Structured Interviews										Source	Cloud Computing	Better Inventory Management and Visibility		Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Implementing Digital Technologies and Automation)	Establishing Metrics and Standards (Supplier and Inventory Management, Compliance and Regulatory Standards, Quality and Reliability)	Resistance to Change
9								Resilience	Case Study										Storage	Internet of Things (IoT)			Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Ensuring Logistics Optimization (Distribution, Last-Mile Delivery)	Regulatory Constraints
9								Smart supply chain	Document Analysis										Deliver	Cyber-Physical Systems (CPS)			Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Inventory Management & Buffer Stocks, Logistics & Distribution Flexibility)	Ensuring Inventory Optimization	Legal Constraints
9																			Return	Artificial Intelligence (AI)			Ensuring Logistics Optimization (Distribution, Last-Mile Delivery)	Ensuring Efficient Resource Allocation (Medical Supplies, Healthcare Equipment and Infrastructure)	
9																				Artificial Intelligence (AI)			Ensuring Inventory Optimization		
9																							Enhancing Real-Time Monitoring and Decision-Making		
10	When Wireless Communication Responds to COVID-19: Combating the Pandemic and Saving the Economy	Saeed, Nasir	2020	Frontiers in Communications and Networks; Volume 1; Article number 566853	Review	Saudi Arabia	36	COVID-19	Systematic Literature Review (SLR)	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85107787928&origin=resultslist&sort=plf-f&src=s&sid=6f63b932a2c32dc2c6df6c1264d2d579&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+digital+technolog*%22+AND+%22risk%22%29&sl=84&sessionSearchId=6f63b932a2c32dc2c6df6c1264d2d579&relpos=0	COVID-19	Demand & Supply Management (Coordination and Logistics)	Ethical and Sustainability Concerns (Inequality in Healthcare and Access)	Financial and Geopolitical Risks (Financial Risks, Geopolitical Risks)	Plan	Medical Consumables	Medical Consumables	Plan	Artificial Intelligence (AI)	Proactive Monitoring and Decision-Making (Environmental & Condition Monitoring; Healthcare & Emergency Response Strategies)	Predictive and Proactive Risk Mitigation	Expanding Access and Building Infrastructure	Ensuring Logistics Optimization (Supply Chain and Demand Management)	Privacy Concerns
10		et al						Digital technologies	Conceptual Framework Development			Biological Cris*	Disruption in Transportation Networks	Regulatory and Compliance Issues (Data and Communication Challenges)	Operational Risks and Digitalization (Cybersecurity and Data Risks, IT and Network Disruptions)	Source	Medical Devices	Medical Devices	Source	Internet of Things (IoT)		Enhanced Data Security and Fraud Prevention	Ensuring Logistics Optimization (Supply Chain and Demand Management)	Ensuring Efficient Resource Allocation (Human Resources, Healthcare Equipment and Infrastructure, Digital and Technological Resources)	Complexity of Implementation
10								E-commerce	Scenario Analysis			Economic Cris*	Inventory Management & Visibility (Logistics and Coordination Challenges)	Quality and Standardization	Data Security and Privacy Risks	Deliver	Pharmaceuticals	Pharmaceuticals	Deliver	Cyber-Physical Systems (CPS)		Compliance and Environmental Risk Management Regulatory and Sustainability Improvement	Ensuring Efficient Resource Allocation (Human Resources, Healthcare Equipment and Infrastructure, Digital and Technological Resources)	Establishing Regulatory Compliance	Security Concerns
10								Healthcare automation	Comparative Analyses			Health Security Cris*	Infrastructure & Capacity Limitations (Data and Communication Challenges)	Cost and Economic Feasibility (Digital and Technological Infrastructure Costs)	Crisis and Urgent Disruption Management	Storage			Storage	Cloud Computing			Strengthening Supply Chain Redundancy and Flexibility (Adaptability & Resilience, Supplier Diversification & Backup, Real-Time Data & Monitoring, Inventory Management & Buffer Stocks, Logistics & Distribution Flexibility)		
10								Virtual education				Industrial Cris*		Supplier Challenges (Supply Chain Stability and Resilience Issues, Financial & Investment Challenges)	Reputational and Customer-Centric Risks (Reputation Impact Risks, Customer Experience and Reliability Risks)										
10								Wireless communication				Technological Cris*													
11	Redefining HCC Surveillance in India: A Call for Innovative and Inclusive Strategies	Yelsangikar, Amit;	2024	Journal of Clinical and Experimental Hepatology; Volume 14; Issue 6; Article number 101474	Review	India	0	Cirrhosis	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85198600935&origin=resultslist&sort=plf-f&src=s&sid=fa1932a4b3fff2a1e57a00b72034dbb&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22logistic%22+AND+%22+digital+technolog*%22+AND+%22risk%22%29&sl=84&sessionSearchId=fa1932a4b3fff2a1e57a00b72034dbb&relpos=1							In Vitro Diagnostics (IVD)	Plan	Artificial Intelligence (AI)	Improved Transparency and Traceability (of Cybersecurity and Secure System Integration)	Predictive and Proactive Risk Mitigation	Expanding Access and Building Infrastructure	Developing and Training the Workforce	Complexity of Implementation
11		et al						Diagnosis	Case Study									Laboratory Supplies	Source	Big Data and Analytics	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Ensuring Logistics Optimization (Supply Chain and Demand Management, Transportation, Distribution)	Ensuring Logistics Optimization (Supply Chain and Demand Management, Transportation, Distribution)	Privacy Concerns
11								Early hepatocellular cancer	Comparative Analyses									Medical Devices	Storage	Cloud Computing	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)		Ensuring Efficient Resource Allocation (Medical supplies, Pharmaceuticals, Healthcare Equipment and Infrastructure)	Ensuring Efficient Resource Allocation (Medical supplies, Pharmaceuticals, Healthcare Equipment and Infrastructure)	Resistance to Change
11								Hepatitis	Empirical Research									Hospital Equipment	Deliver	Internet of Things (IoT)			Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Real-Time Data & Monitoring, Inventory Management & Buffer Stocks, Inventory Management & Buffer Stocks)		Costs (Initial Investment Costs)
11								Surveillance										Pharmaceuticals					Enhancing Real-Time Monitoring and Decision-Making		
12	Securing the IoT Landscape: A Comprehensive Review of Secure Systems in the Digital Era	Siraparapu, Sri Ramya	2024	e-Prime - Advances in Electrical Engineering, Electronics and Energy; Volume 10; Article number 100798	Article	India	0	Applications of IoT secure system	Literature Review	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85205513534&origin=resultslist&sort=plf-f&src=s&sid=fa1932a4b3fff2a1e57a00b72034dbb&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT+%22+AND+%22resilience%22%29&sl=84&sessionSearchId=fa1932a4b3fff2a1e57a00b72034dbb&relpos=2							All	Plan	Internet of Things (IoT)	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Enhanced Data Security and Fraud Prevention	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Strengthening Communication and Digital Collaboration, Implementing Digital Technologies and Automation)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Health-Related Data, Supply Chain and Transaction Data)	Complexity of Implementation
12		et al						Industry 4.0	Case Study										Source	Cloud Computing	Proactive Monitoring and Decision-Making (IoT & Security Monitoring; Security & Data Protection)	Predictive and Proactive Risk Mitigation	Enhancing Real-Time Monitoring and Decision-Making	Adopting Secure Coding Practices (Secure Coding Practices)	Resistance to Change
12								Internet of Things	Empirical Research										Storage	Blockchain			Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Developing and Training the Workforce	Privacy Concerns
12								IoT secure system standards											Deliver	Artificial Intelligence (AI)				Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
12								IoT trust models												Cyber Security				Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Costs (Scalability and Integration Costs, Security and Privacy Costs)
12								Secure System Architecture												Big Data and Analytics				Strengthening Data Security and Privacy	Regulatory Constraints
12																								Developing Predictive and Risk Mitigation Models	

Paper n.	Title of the article	Author(s)	Publication date	Name of journal/conference, volume, issue, book, page numbers	Publication type	Country of affiliation of the first author	N. citations (Scopus)	Author Keywords	Methodology	Methodology type	Scopus Link	Identified cris*	Main logistic challenges	Main procurement challenges	Main risk management challenges	Supply chain process	Type of products	Type of products.	Supply chain process.	Digital technologies	Resilience improvements	Risk management improvements	Defined actions to improve resilience	Defined actions to improve risk management	Limits/Difficulties of integration of digital technologies
13	Secured Blockchain Technology for Medical Supply Chain (SB-MSC)	Sumalatha M.R.	2024	2024 International Conference on Advances in Data Engineering and Intelligent Computing Systems, ADICS 2024	Conference Paper	India	0	Blockchain	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85195179206&origin=resultslist&sort=plf-f&src=s&sid=fa1932a4b3ffff2a1e57a00b72034dbb&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sl=84&sessionSearchId=fa1932a4b3ffff2a1e57a00b72034dbb&relpos=5	COVID-19	Quality Assurance & Scheduling	Data and Communication Challenges	Real-Time Monitoring and Mitigation	Plan	Pharmaceuticals	Pharmaceuticals	Plan	Internet of Things (IoT)	Proactive Monitoring and Decision-Making (Environmental & Condition Monitoring; Logistics & Inventory Optimization)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Costs (Initial Investment Costs, Development and Adaptation Costs)
13		et al						Data Analysis	Mathematical Model Development				Disruption in Transportation Networks	Cost and Economic Feasibility (Digital and Technological Infrastructure Costs, Supply Chain Costs)	Reputational and Customer-Centric Risks (Customer Experience and Reliability Risks)	Source	Medical Consumables	Medical Consumables	Source	Blockchain	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Enhanced Data Security and Fraud Prevention	Building Collaborative and Transparent Ecosystems (Blockchain Ecosystems)	Ensuring Inventory Optimization	Complexity of Implementation
13								Healthcare	Optimization Model Development				Inventory Management & Visibility (Demand and Inventory Management Challenges, Data and Tracking Challenges)	Quality and Standardization	Data Security and Privacy Risks	Deliver			Deliver	Artificial Intelligence (AI)	Improved Transparency and Traceability (of Supply Chain Operations and Processes, Environmental Conditions)		Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Implementing Digital Technologies and Automation)	Ensuring Logistics Optimization (Last-Mile Delivery,Transportation)	Privacy Concerns
13								Internet of Things (IoT)	Simulation Model Development						Supply Chain and Logistics Risks (Transportation and Distribution Disruptions, Operational and Coordination Challenges)	Storage			Storage	Big Data and Analytics			Strengthening Supply Chain Redundancy and Flexibility (Logistics & Distribution Flexibility, Real-Time Data & Monitoring, Communication & Backup Systems, Automation & Decision-Making, Supply Chain Transparency & Security, Data & Communication Challenges)		
13								Pharmaceuticals	Prediction Model														Ensuring Inventory Optimization		
13								SCM Framework	Scenario Analysis																
13									Conceptual Framework																
14	Reshaping healthcare supply chain using chain-of-things technology and key lessons experienced from COVID-19 pandemic	Sathiya V.	2023	Socio-Economic Planning Sciences; Volume 85; Article number 101510	Article	India	11	Blockchain technology	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85146460011&origin=resultslist&sort=plf-f&src=s&sid=fa1932a4b3ffff2a1e57a00b72034dbb&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sl=84&sessionSearchId=fa1932a4b3ffff2a1e57a00b72034dbb&relpos=13	COVID-19	Disruption in Supply Chain Networks	Demand and Strategic Procurement Issues (Fluctuating Demand & Unpredictability, Procurement & Supply Balancing Challenges, Inefficiencies in Supplier & Logistics Coordination)	Operational Risks and Digitalization (Cybersecurity and Data Risks, System and Technology Integration Risks)	Plan	Medical Devices	Medical Devices	Plan	Internet of Things (IoT)	Improved Transparency and Traceability (of Environmental Conditions)	Predictive and Proactive Risk Mitigation	Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Inventory Management & Buffer Stock, Real-Time Data & Monitoring)	Ensuring Logistics Optimization (Distribution, Supply Chain and Demand Management)	Complexity of Implementation
14		et al						Chain of things	Fuzzy DEMATEL				Supply Chain Vulnerabilities (Fluctuations in Demand, Supply Chain Instability)			Source	Medical Consumables	Medical Consumables	Source	Big Data and Analytics	Proactive Monitoring and Decision-Making (Environmental & Condition Monitoring; Supply Chain Resilience & Risk Management		Enhancing Real-Time Monitoring and Decision-Making	Ensuring Efficient Resource Allocation (Medical Supplies, Human Resources)	Costs (Development and Adaptation Costs, Scalability and Integration Costs)
14								Healthcare supply chain								Storage	In Vitro Diagnostics (IVD)	In Vitro Diagnostics (IVD)	Storage	Blockchain			Ensuring Efficient Resource Allocation (Medical Supplies, Human Resources)	Ensuring Inventory Optimization	
14								Internet of things								Deliver	Pharmaceuticals	Pharmaceuticals	Deliver				Ensuring Inventory Optimization		
14								Localization																	
14								Resilient supply chain																	
14								Reverse logistics																	
15	A review of Smart Contract-based platforms, applications, and challenges	Sharma, Pratima	2023	Cluster Computing; Volume 26; Issue 1; Pages 395 - 421	Article	India	38	Blockchain	Systematic Literature Review (SLR)	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85123242877&origin=resultslist&sort=plf-f&src=s&sid=fa1932a4b3ffff2a1e57a00b72034dbb&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sl=84&sessionSearchId=fa1932a4b3ffff2a1e57a00b72034dbb&relpos=14							Pharmaceuticals	Source	Blockchain	Improved Transparency and Traceability (of Pharmaceuticals)	Enhanced Data Security and Fraud Prevention	Enhancing Real-Time Monitoring and Decision-Making	Protecting Sensitive Data with Encryption and Security Measures (Health-Related Data, Supply Chain and Transaction Data)	Complexity of Implementation
15		et al						Distributed applications	Comparative Analysis									Medical Devices	Deliver	Artificial Intelligence (AI)	Proactive Monitoring and Decision-Making (IoT & Security Monitoring; Supply Chain Resilience & Risk Management)	Predictive and Proactive Risk Mitigation	Building Collaborative and Transparent Ecosystems (Supply Chain and Healthcare Ecosystems)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Privacy Concerns
15								Platforms	Content Analysis									In Vitro Diagnostics (IVD)	Enable	Internet of Things (IoT)	Better Inventory Management and Visibility		Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Logistics & Distribution Flexibility, Inventory Management & Buffer Stocks, Real-Time Data & Monitoring)	Strengthening Data Security and Privacy	Security Concerns
15								Smart Contract	Thematic Analysis									Medical Consumables	Storage	Cyber Security			Ensuring Inventory Optimization	Ensuring Logistics Optimization (Supply Chain and Demand Management, Transportation, Distribution)	Regulatory Constraints
15									Bibliometric Analysis									Hospital Equipment						Ensuring Inventory Optimization	Legal Constraints
15									Citation Network Analysis																Resistance to Change
15																									Costs (Initial Investment Costs)
16	IoE Security Risk Analysis in a Modern Hospital Ecosystem	Jimo, Sadiat	2023	Advanced Sciences and Technologies for Security Applications	Book Chapter	United Kingdom	5	Attacks	Literature Review	Mixed	https://www.scopus.com/record/display.uri?eid=2-s2.0-85146232355&origin=resultslist&sort=plf-f&src=s&sid=d1771436d74427dd4415c522b8c56b69&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sl=69&sessionSearchId=d1771436d74427dd4415c522b8c56b69&relpos=27							Pharmaceuticals	Deliver	Internet of Things (IoT)	Proactive Monitoring and Decision-Making (IoT & Security Monitoring Security & Data Protection)	Predictive and Proactive Risk Mitigation	Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Communication & Backup Systems)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Patient and Medical Records, Other Sensitive Data)	Complexity of Implementation
16		et al						Internet of Everything	Case Study									Medical Devices	Source	Big Data and Analytics		Enhanced Data Security and Fraud Prevention	Adopting Patch Management	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
16								Preventive Measures	Empirical Research									Medical Consumables	Storage	Artificial Intelligence (AI)			Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Privacy Concerns
16								Privacy										Hospital Equipment	Plan	Cyber-Physical Systems (CPS)				Developing Predictive and Risk Mitigation Models	Resistance to Change
16								Security												Cloud Computing					
16								Threats												Digital Simulation-Digital Twin					
17	IoT-driven Smart Packaging for Pharmaceuticals: Ensuring Product Integrity and Patient Safety	Raman, Ramakrishnan	2023	International Conference on Artificial Intelligence for Innovations in Healthcare Industries, ICAIIHI 2023; Pages 1-6(?)	Conference Paper	India	23	Healthcare Applications	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85191512444&origin=resultslist&sort=plf-f&src=s&sid=fa1932a4b3ffff2a1e57a00b72034dbb&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sl=84&sessionSearchId=fa1932a4b3ffff2a1e57a00b72034dbb&relpos=15							Pharmaceuticals	Source	Internet of Things (IoT)	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Developing Predictive and Risk Mitigation Models	Complexity of Implementation
17		et al						Real-time Monitoring	Conceptual Framework										Storage	Big Data and Analytics	Better Inventory Management and Visibility		Strengthening Supply Chain Redundancy and Flexibility (Logistics & Distribution Flexibility, Adaptability & Resilience, Risk Reduction & Fraud Prevention)	Building Collaborative and Transparent Ecosystems (Supply Chain and Healthcare Ecosystems, IoT and Digital Ecosystems, Collaborative and Data-Sharing Ecosystems)	Privacy Concerns
17								Smart Packaging	Empirical Research										Deliver	Cloud Computing	Proactive Monitoring and Decision-Making (Environmental & Condition Monitoring; Security & Data Protection)		Ensuring Inventory Optimization	Ensuring Inventory Optimization	Security Concerns
17								Supply Chain Management	Simulation Model Development											Cyber-Physical Systems (CPS)			Ensuring Efficient Resource Allocation (Pharmaceuticals, Human Resources)	Ensuring Efficient Resource Allocation (Pharmaceuticals, Human resources)	Legal Constraints
17								Wireless Communication												Cyber Security				Ensuring Logistics Optimization (Supply Chain and Demand Management, Last-Mile Delivery)	Resistance to Change
17																								Establishing Regulatory Compliance	Costs (Financial and Economic Costs, Ongoing Operational and Maintenance Costs, Regulatory and Compliance Costs, Development and Adaptation Costs)
18	Revolutionizing Industries Through IoT, Blockchain and AI Integration	Suji Priya J.	2023	Proceedings - 2023 3rd International Conference on Pervasive Computing and Social Networking, ICPCSN 2023; Pages 972 - 977	Conference Paper	India	1	Artificial Intelligence (AI)	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85175245089&origin=resultslist&sort=plf-f&src=s&sid=644726191cdf92f0600026c91ae271b3&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sl=69&sessionSearchId=644726191cdf92f0600026c91ae271b3&relpos=21							All	Plan	Internet of Things (IoT)	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Enhancing Real-Time Monitoring and Decision-Making	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Privacy Concerns
18		et al						Blockchain	Case Study										Source	Blockchain	Improved Transparency and Traceability (of Environmental Conditions, Supply Chain Operations and Processes)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Implementing Digital Technologies and Automation, Strengthening Communication and Digital Collaboration, Enhancing Monitoring and Optimization)	Establishing Regulatory Compliance	Security Concerns
18								Internet of Things (IoT)	Conceptual Framework										Storage	Artificial Intelligence (AI)		Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Building Collaborative and Transparent Ecosystems (Supply Chain and Healthcare Ecosystems, Decentralized and Traceability Ecosystems, Collaborative and Data-Sharing Ecosystems)	Building Collaborative and Transparent Ecosystems (Supply Chain and Healthcare Ecosystems, Decentralized and Traceability Ecosystems, Collaborative and Data-Sharing Ecosystems)	Complexity of Implementation
18								supply chain	Semi-Structured Interviews										Deliver				Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Logistics & Distribution Flexibility, Inventory Management & Buffer Stocks, Real-Time Data & Monitoring)	Ensuring Logistics Optimization (Transportation, Warehousing, Last-Mile Delivery)	Costs (Initial Investment Costs, Ongoing Operational and Maintenance Costs, Scalability and Integration Costs, Regulatory and Compliance Costs, Miscellaneous Costs)
18								integration	Conceptual Framework Development										Return				Ensuring Logistics Optimization (Transportation, Warehousing, Last-Mile Delivery)		Regulatory Constraints
18									Citation Network Analysis																Legal Constraints
18									Meta-Analysis																
18									Bibliometric Analysis																
18									Empirical Research																

Paper n.	Title of the article	Author(s)	Publication date	Name of journal/conference, volume, issue, book, page numbers	Publication type	Country of affiliation of the first author	N. citations (Scopus)	Author Keywords	Methodology	Methodology type	Scopus Link	Identified cris*	Main logistic challenges	Main procurement challenges	Main risk management challenges	Supply chain process	Type of products	Type of products.	Supply chain process.	Digital technologies	Resilience improvements	Risk management improvements	Defined actions to improve resilience	Defined actions to improve risk management	Limits/Difficulties of integration of digital technologies
19	Blockchain Technology: Opportunities & Challenges	Bilal, Khushnood	2022	2022 International Conference on Data Analytics for Business and Industry, ICDABI 2022; Pages 519 - 524	Conference Paper	India	29	Blockchain Technology	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85149333982&origin=resultslist&sort=plf-f&src=s&sid=644726191cdf92f0600026c91ae271b3&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sl=69&sessionSearchId=644726191cdf92f0600026c91ae271b3&relpos=14							Pharmaceuticals	Deliver	Blockchain	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Enhanced Data Security and Fraud Prevention	Expanding Access and Building Infrastructure	Building Collaborative and Transparent Ecosystems (Supply Chain and Healthcare Ecosystems, Blockchain Ecosystems, IoT and Digital Ecosystems)	Complexity of Implementation
19		et al						Consensus Mechanism	Case Study									Medical Devices	Plan	Artificial Intelligence (AI)		Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration, Implementing Digital Technologies and Automation, Enhancing Monitoring and Optimization)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Privacy Concerns
19								Consortium	Conceptual Framework Development									Medical Consumables	Source	Internet of Things (IoT)			Enhancing Real-Time Monitoring and Decision-Making	Protecting Sensitive Data with Encryption and Security Measures (Security and Privacy Measures, Health-Related Data)	Security Concerns
19								Deployment Models	Bibliometric Analysis										Storage	Cloud Computing			Strengthening Supply Chain Redundancy and Flexibility (Inventory Management & Buffer Stocks, Supplier Diversification & Backup, Logistics & Distribution Flexibility, Inventory Management & Buffer Stocks)	Ensuring Logistics Optimization (Transportation, Last-Mile Delivery, Warehousing)	Costs (Ongoing Operational and Maintenance Costs, Scalability and Integration Costs, Security and Privacy Costs)
19								Hybrid	Meta-Analysis														Building Collaborative and Transparent Ecosystems (Supply Chain and Healthcare Ecosystems, Blockchain Ecosystems, IoT and Digital Ecosystems)	Strengthening Data Security and Privacy	Regulatory Constraints
19								Private	Empirical Research															Establishing Regulatory Compliance	Resistance to Change
19								Public																	
20	Securing Internet of Things devices by enabling Ethereum blockchain using Smart Contracts	Patruni, Muralidhara Rao	2022	Building Services Engineering Research and Technology; Volume 43; Issue 4; Pages 473 - 484	Article	India	8	Authentication	Literature Review	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85129145495&origin=resultslist&sort=plf-f&src=s&sid=644726191cdf92f0600026c91ae271b3&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sl=69&sessionSearchId=644726191cdf92f0600026c91ae271b3&relpos=19							Medical Devices	Source	Cloud Computing	Building a Resilient Supply Chain	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Adaptability & Resilience, Communication & Backup Systems)	Protecting Sensitive Data with Encryption and Security Measures (Security and Privacy Measures)	Complexity of Implementation
20		et al						Internet of Things	Conceptual Framework Development										Deliver	Blockchain	Proactive Monitoring and Decision-Making (IoT & Security Monitoring; Security & Data Protection)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Costs (Ongoing Operational and Maintenance Costs, Security and Privacy Costs)
20								Key management	Case Study										Storage	Internet of Things (IoT)			Building Collaborative and Transparent Ecosystems(IoT and Digital Ecosystems, Blockchain Ecosystems, Collaborative and Data-Sharing Ecosystems)	Strengthening Data Security and Privacy	
20								Privacy	Simulation Model Development										Enable	Cyber Security				Building Collaborative and Transparent Ecosystems(IoT and Digital Ecosystems, Blockchain Ecosystems, Collaborative and Data-Sharing Ecosystems)	
20								Security	Mathematical Model Development																
20									Empirical Research																
21	Systematic Analysis of Risk Associated with Supply Chain Operations Using Blockchain Technology	Khan, Habib Ullah	2022	Wireless Communications and Mobile Computing; Volume 2022; Article number 6916048	Review	Qatar	2	...	Systematic Literature Review (SLR)	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85137684768&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sessionSearchId=dc26c7b3dff88e3d22b4a62432e95d56&relpos=31							Pharmaceuticals	Plan	Internet of Things (IoT)	Improved Transparency and Traceability (of Supply Chain Operations and Processes, Movement and Tracking)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration)	Protecting Sensitive Data with Encryption and Security Measures (Supply Chain and Transaction Data, Other Sensitive Data)	Privacy Concerns
21		et al							Conceptual Framework									Medical Devices	Source	Big Data and Analytics		Enhanced Data Security and Fraud Prevention	Enhancing Real-Time Monitoring and Decision-Making	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
21									Comparative Analysis									Medical Consumables	Storage	Cloud Computing			Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Strengthening Data Security and Privacy	Regulatory Constraints
21									Content Analysis										Deliver	Cyber Security			Ensuring Efficient Resource Allocation (Data and Information Resources)	Establishing Metrics and Standards (Performance and Efficiency Metrics; Data Integrity, Security, and Privacy Standards)	Costs (Initial Investment Costs, Ongoing Operational and Maintenance Costs)
21																			Return	Artificial Intelligence (AI)				Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Complexity of Implementation
21																			Enable	Blockchain				Establishing Regulatory Compliance	
21																				Cyber-Physical Systems (CPS)					
21																									
21																									
22	Internet of Things (IoT) in high-risk Environment, Health and Safety (EHS) industries: A comprehensive review	Thibaud, Montbel	2018	Decision Support Systems; Volume 108; Pages 79 - 95	Article	France	196	Connected vehicles	Systematic Literature Review (SLR)	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85042623024&origin=resultslist&sort=plf-f&src=s&sid=644726191cdf92f0600026c91ae271b3&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sl=69&sessionSearchId=644726191cdf92f0600026c91ae271b3&relpos=2							Medical Devices	Deliver	Internet of Things (IoT)	Proactive Monitoring and Decision-Making (Environmental & Condition Monitoring; Supply Chain Resilience & Risk Management)	Predictive and Proactive Risk Mitigation	Strengthening Supply Chain Redundancy and Flexibility (Adaptability & Resilience, Communication & Backup Systems)	Adopting Secure Coding Practices (Cybersecurity and Privacy)	Costs (Ongoing Operational and Maintenance Costs, Scalability and Integration Costs, Security and Privacy Costs, Training and Adoption Costs, Financial and Economic Costs)
22		et al						Environment Health and Safety (EHS)	Bibliometric Analysis										Storage	Artificial Intelligence (AI)		Enhanced Data Security and Fraud Prevention	Enhancing Real-Time Monitoring and Decision-Making	Protecting Sensitive Data with Encryption and Security Measures (Patient and Medical Records, Personal and Sensitive Information, Other Sensitive Data)	Complexity of Implementation
22								Food supply chain	Citation Network Analysis											Cloud Computing		Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Leveraging Digital Technologies for Resilience (by Implementing Digital Technologies and Automation, Enhancing Monitoring and Optimization, Strengthening Communication and Digital Collaboration)	Ensuring Efficient Resource Allocation (Digital and Technological Resources)	Security Concerns
22								Healthcare												Big Data and Analytics	.		Expanding Access and Building Infrastructure	Ensuring Logistics Optimization (Supply Chain and Demand Management, Distribution)	
22								Internet of Things (IoT)												Cyber-Physical Systems (CPS)			Ensuring Efficient Resource Allocation (Digital and Technological Resources)		
22								Smart city												Cyber Security					
23	Supply chain management in the era of the internet of things	Zhou, Li	2015	International Journal of Production Economics; Volume 159; Pages 1-3	Editorial	United Kingdom	72	Framework development	Systematic Literature Review	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-84915735391&origin=resultslist&sort=plf-f&src=s&sid=644726191cdf92f0600026c91ae271b3&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+IoT%22+AND+%22risk%22%29&sl=69&sessionSearchId=644726191cdf92f0600026c91ae271b3&relpos=0							All	Plan	Internet of Things (IoT)	Proactive Monitoring and Decision-Making (Environmental & Condition Monitoring; Supply Chain Resilience & Risk Management)	Predictive and Proactive Risk Mitigation	Building Collaborative and Transparent Ecosystems (IoT and Digital Ecosystems)	Ensuring Logistics Optimization (Supply Chain and Demand Management, Warehousing, Transportation)	Costs (Ongoing Operational and Maintenance Costs, Miscellaneous Costs, Development and Adaptation Costs, Training and Adoption Costs)
23		et al						Simulations	Case Study										Enable	Artificial Intelligence (AI)	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)		Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration, Implementing Digital Technologies and Automation, Enhancing Monitoring and Optimization)	Ensuring Efficient Resource Allocation (Healthcare Equipment and Infrastructure, Human Resources, Data and Information Resources)	Complexity of Implementation
23								Empirical modeling	Survey										Deliver	Cloud Computing	Better Inventory Management and Visibility		Enhancing Real-Time Monitoring and Decision-Making	Establishing Regulatory Compliance	Privacy Concerns
23								Comparative analysis	Action Research										Storage				Ensuring Efficient Resource Allocation (Healthcare Equipment and Infrastructure, Human Resources, Data and Information Resources)		Security Concerns
23								Case studies	Simulation Model Development																Resistance to Change
23									Structural Equation Modeling (SEM)																
23									Simulations																
23									Comparative Analyses																
24	A Bi-objective location-routing model for the healthcare waste management in the era of logistics 4.0 under uncertainty	Govindan, Kannan	2024	International Journal of Production Economics; Volume 276; Article number 109342	Article	China	2	Electric autonomous vehicle	Systematic Literature Review (SLR)	Quantitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85200048956&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22logistic%22+AND+%22+IoT%22+AND+%22risk%22%29&sessionSearchId=918d15426edeef376dee7b8ecb9b2485&relpos=4							Products for The Management of Medical Waste	Plan	Internet of Things (IoT)	Improved Transparency and Traceability (of Pharmaceuticals)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization)	Protecting Sensitive Data with Encryption and Security Measures (Security and Privacy Measures)	Privacy Concerns
24		et al						Fuzzy theory	Mathematical Model Development										Source	Blockchain	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Developing Predictive and Risk Mitigation Models	Security Concerns
24								Healthcare waste management	Optimization Model Development										Storage	Cyber-Physical Systems (CPS)			Building Collaborative and Transparent Ecosystems (IoT and Digital Ecosystems, Supply Chain and Healthcare Ecosystems)	Building Collaborative and Transparent Ecosystems (IoT and Digital Ecosystems, Supply Chain and Healthcare Ecosystems)	Costs (Initial Investment Costs, Scalability and Integration Costs, Training and Adoption Costs, Regulatory and Compliance Costs)
24								Location-routing problem	Case Study										Deliver				Ensuring Efficient Resource Allocation (Medical Supplies, Inventory and Logistics Resources)	Establishing Regulatory Compliance	Complexity of Implementation
24								Logistics 4.0	Empirical Research										Enable						Regulatory Constraints
24									Simulation Model Development																Resistance to Change
24									Prediction Model																

Paper n.	Title of the article	Author(s)	Publication date	Name of journal/conference, volume, issue, book, page numbers	Publication type	Country of affiliation of the first author	N. citations (Scopus)	Author Keywords	Methodology	Methodology type	Scopus Link	Identified cris*	Main logistic challenges	Main procurement challenges	Main risk management challenges	Supply chain process	Type of products	Type of products.	Supply chain process.	Digital technologies	Resilience improvements	Risk management improvements	Defined actions to improve resilience	Defined actions to improve risk management	Limits/Difficulties of integration of digital technologies
25	The Drivers of Complexity in Inventory Management Within the Healthcare Industry: A Systematic Review	Khatib, Inas Al	2024	International Journal of Service Science, Management, Engineering, and Technology; Volume 15; Issue 1; Pages1-26 (?)	Article	United Arab Emirates	1	Economic Order Quantity Model	Systematic Literature Review (SLR)	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85195509992&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22AND+%22+supply+chain%22+AND+%22++Blockchain%22+AND+%22resilience%22%29&sessionSearchId=ba858a394cf3a41e671560b89f249057&relpos=12	COVID-19	Demand & Supply Management (Supply and Demand Issues, Supply Chain Efficiency)	Cost and Economic Feasibility (Transportation and Distribution Costs, Specific Supply Chain Costs)	Supply Chain and Logistics Risks (Transportation and Distribution Disruptions, Regulatory and Compliance Risks, Storage and Inventory Management Issues	Plan	Pharmaceuticals	Pharmaceuticals	Plan	Internet of Things (IoT)	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Strengthening Communication and Digital Collaboration)	Ensuring Inventory Optimization	Costs (Initial Investment Costs, Scalability and Integration Costs, Training and Adoption Costs, Regulatory and Compliance Costs)
25		et al						Healthcare	Bibliometric Analysis				Infrastructure & Capacity Limitations (Resource and Material Availability)	Ethical and Sustainability Concerns (Environmental Sustainability,Transparency and Fair Practices)		Enable	Medical Devices	Medical Devices	Enable	Big Data and Analytics	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)		Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems, Supply Chain and Healthcare Ecosystems, IoT and Digital Ecosystems)	Ensuring Logistics Optimization (Supply Chain and Demand Management, Warehousing, Transportation)	Security Concerns
25								Inventory Management	Citation Network Analysis				Inventory Management & Visibility (Data and Tracking Challenges, Demand and Inventory Management Challenges, Cost and Efficiency Issues)	Supplier Challenges (Supply Chain Stability and Resilience Issues, Financial & Investment Challenges)		Deliver	Medical Consumables	Medical Consumables	Deliver	Blockchain			Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Inventory Management & Buffer Stocks, Logistics & Distribution Flexibility)		Complexity of Implementation
25								Just-In-Time Methodology	Content Analysis				Supply Chain Vulnerabilities (Supply Chain Instability, Supply Shortages and Unpredictability, Fluctuations in Demand, Distribution and Transport Bottlenecks)			Storage			Storage	Artificial Intelligence (AI)			Enhancing Real-Time Monitoring and Decision-Making		Resistance to Change
25								Lean Supply Chain	Thematic Analysis							Source			Source	Cloud Computing			Ensuring Inventory Optimization		
25								Reorder Point Method;																	
25								Supply Chain Management																	
25								Technology																	
26	A fuzzy optimization-oriented decision support model to examine key industry 4.0 strategies for building resilience against disruptions in a healthcare supply chain	Kayhan, Behice Meltem	2024	Annals of Operations Research; Article number 105968	Article	Turkey	0	Common goods	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85213309746&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22resilience%22%29&relpos=6	Natural Cris*	Disruption in Transportation Networks	Supplier Challenges (Supply Chain Stability and Resilience Issues)	Regulatory and Policy Challenges	Storage	Pharmaceuticals	Pharmaceuticals	Storage	Internet of Things (IoT)	Improved Transparency and Traceability (of Medical Supplies)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization)	Protecting Sensitive Data with Encryption and Security Measures (Patient and Medical Records, Health-Related Data, Supply Chain and Transaction Data)	Costs (Initial Investment Costs, Training and Adoption Costs, Security and Privacy Costs, Ongoing Operational and Maintenance Costs)
26		et al						Healthcare supply chain	Optimization Model Development			Biological Cris*	Supply Chain Vulnerabilities (Supply Shortages and Unpredictability, Infrastructure Weaknesses, Disruption in Transportation Networks)	Resource and Material Availability	Risks Related to Health and Safety	Enable	Medical Devices	Medical Devices	Enable	Blockchain	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Enhancing Real-Time Monitoring and Decision-Making	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Complexity of Implementation
26								Industry 4.0	Multi-Criteria Decision-Making Model			Technological Cris*	Demand & Supply Management (Supply and Demand Issues, Coordination and Logistics, Supply Chain Efficiency)	Regulatory and Compliance Issues (Transportation and Distribution Regulations, Regulatory and Compliance Issues)	Crisis and Urgent Disruption Management		Medical Consumables	Medical Consumables		Digital Simulation-Digital Twin	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Ensuring Efficient Resource Allocation (Medical Supplies, Inventory and Logistics Resources)	Adopting Secure Coding Practices (Cybersecurity and Privacy)	Privacy Concerns
26								Resilience	Case Study			Geopolitical Cris*	Inventory Management & Visibility (Demand and Inventory Management Challenges, Data and Tracking Challenges, Logistics and Coordination Challenges, Cost and Efficiency Issues)	Quality and Standardization	Real-Time Monitoring and Mitigation		Laboratory Supplies	Laboratory Supplies		Artificial Intelligence (AI)	Enhanced Data Security		Ensuring Inventory Optimization	Strengthening Data Security and Privacy	Security Concerns
26								SCOR					Quality Assurance & Scheduling	Demand and Strategic Procurement Issues (Fluctuating Demand & Unpredictability, Procurement & Supply Balancing Challenges)	Operational Risks and Digitalization (System and Technology Integration Risks, IT and Network Disruptions)									Establishing Metrics and Standards (Performance and Efficiency Metrics; Data Integrity, Security, and Privacy Standards)	Regulatory Constraints
26															Supply Chain and Logistics Risks (Transportation and Distribution Disruptions, Storage and Inventory Management Issues, Demand and Supply Uncertainties)									Developing Predictive and Risk Mitigation Models	Resistance to Change
26																								Developing and Training the Workforce	Policy Constraints
26																								Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	
26																								Developing Predictive and Risk Mitigation Models	
26																								Establishing Regulatory Compliance	
27	Exploring the effect of blockchain technology on supply chain resilience and transparency: Evidence from the healthcare industry	Alabaddi, Zaid	2023	Uncertain Supply Chain Management; Volume 11; Issue 2; Pages 787 - 798	Article	Jordan	6	Blockchain technology	Literature Review	Quantitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85151434607&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22AND+%22+supply+chain%22+AND+%22++Blockchain%22+AND+%22resilience%22%29&sessionSearchId=ba858a394cf3a41e671560b89f249057&relpos=8	Technological Cris*	Supply Chain Vulnerabilities (Supply Chain Instability, Supply Shortages and Unpredictability, Infrastructure Weaknesses)	Regulatory and Compliance Issues (Transportation and Distribution Regulations, Regulatory and Compliance Issues)	Data Security and Privacy Risks	Plan	Pharmaceuticals	Pharmaceuticals	Plan	Blockchain	Improved Transparency and Traceability (of Environmental Conditions)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Supply Chain and Transaction Data)	Privacy Concerns
27		et al						Data quality	Survey			COVID-19	Inventory Management & Visibility (Demand and Inventory Management Challenges, Data and Tracking Challenges, Logistics and Coordination Challenges)	Quality and Standardization	Supply Chain and Logistics Risks (Transportation and Distribution Disruptions, Demand and Supply Uncertainties)	Source	Medical Consumables	Medical Consumables	Source		Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Adaptability & Resilience, Communication & Backup Systems)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
27								Smart Contracts	Empirical Research						Crisis and Urgent Disruption Management	Storage			Storage		Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Adopting Secure Coding Practices (Cybersecurity and Privacy)	Regulatory Constraints
27								Supply chain resilience	Structural Equation Modeling (SEM)							Deliver			Deliver		Enhanced Data Security		Building Collaborative and Transparent Ecosystems (Blockchain Ecosystems)	Strengthening Data Security and Privacy	Legal Constraints
27								Supply chain transparency								Enable			Enable				Expanding Access and Building Infrastructure	Establishing Metrics and Standards (Performance and Efficiency Metrics)	Costs (Initial Investment Costs, Miscellaneous Costs)
27								Traceability															Ensuring Efficient Resource Allocation (Data and Information Resources, Inventory and Logistics Resources, Inventory and Logistics Resource)	Developing Predictive and Risk Mitigation Models	Complexity of Implementation
27																							Ensuring Inventory Optimization	Developing and Training the Workforce	Resistance to Change
27																								Building Collaborative and Transparent Ecosystems (Blockchain Ecosystems)	Policy Constraints
27																								Establishing Regulatory Compliance	
28	Identifying resilience strategies for disruption management in the healthcare supply chain during COVID-19 by digital innovations: A systematic Literature Review	Arji, Goli	2023	Informatics in Medicine Unlocked; Volume 38; Article number 101199	Review	Iran	32	COVID-19	Systematic Literature Review (SLR)	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85149069886&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22AND+%22+supply+chain%22+AND+%22++Blockchain%22+AND+%22resilience%22%29&sessionSearchId=ba858a394cf3a41e671560b89f249057&relpos=6	COVID-19	Supply Chain Vulnerabilities (Supply Shortages and Unpredictability, Infrastructure Weaknesses, Distribution and Transport Bottlenecks)	Resource and Material Availability	Operational Risks and Digitalization (System and Technology Integration Risks, Operational and Logistical Risks, Cybersecurity and Data Risks)	Plan	Pharmaceuticals	Pharmaceuticals	Plan	Internet of Things (IoT)	Improved Transparency and Traceability (of Medical Supplies)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Implementing Digital Technologies and Automation, Enhancing Monitoring and Optimization)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Supply Chain and Transaction Data, Patient and Medical Records)	Security Concerns
28		et al						Healthcare supply chain				Biological Cris*	Demand & Supply Management (Supply and Demand Issues, Coordination and Logistics, Supply Shortages/Disruptions)	Regulatory and Compliance Issues (Transportation and Distribution Regulations, Regulatory and Compliance Issues)	Supply Chain and Logistics Risks (Transportation and Distribution Disruptions, Demand and Supply Uncertainties, Operational and Coordination Challenges)	Source	Medical Consumables	Medical Consumables	Source	Big Data and Analytics	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Adaptability & Resilience, Supplier Diversification & Backup, Supply Chain Transparency & Security)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Regulatory Constraints
28								Literature Review					Inventory Management & Visibility (Demand and Inventory Management Challenges, Data and Tracking Challenges, Logistics and Coordination Challenges)	Data and Communication Challenges	Crisis and Urgent Disruption Management	Storage	Hospital Equipment	Hospital Equipment	Storage	3D Printing (Additive Manufacturing)	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)		Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Costs (Financial and Economic Costs, Ongoing Operational and Maintenance Costs, Miscellaneous Costs)
28								Pandemics								Deliver			Deliver	Cloud Computing	Enhanced Data Security		Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Establishing Metrics and Standards (Performance and Efficiency Metrics, Supplier and Inventory Management, Quality and Reliability, Compliance and Regulatory Standards)	Complexity of Implementation
28								Supply chain management								Enable			Enable	Digital Simulation-Digital Twin			Expanding Access and Building Infrastructure	Developing Predictive and Risk Mitigation Models	Resistance to Change
28																				Cyber Security			Ensuring Efficient Resource Allocation (Healthcare Equipment and Infrastructure, Financial Resources)	Developing and Training the Workforce	Policy Constraints
28																				Artificial Intelligence (AI)			Ensuring Inventory Optimization	Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	
28																				Blockchain				Establishing Regulatory Compliance	
29	Improving End-to-End Traceability and Pharma Supply Chain Resilience using Blockchain	Sim, Corrine	2022	Blockchain in Healthcare Today; Volume 5; Article number 231	Article	Singapore	10	blockchain	Systematic Literature Review (SLR)	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85142481386&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22AND+%22+supply+chain%22+AND+%22++Blockchain%22+AND+%22resilience%22%29&sessionSearchId=ba858a394cf3a41e671560b89f249057&relpos=3	Biological Cris*	Supply Chain Vulnerabilities (Supply Shortages and Unpredictability, Infrastructure Weaknesses)	Regulatory and Compliance Issues (Transportation and Distribution Regulations, Regulatory and Compliance Issues)	Data Security and Privacy Risks	Plan	Pharmaceuticals	Pharmaceuticals	Plan	Blockchain	Improved Transparency and Traceability (of Pharmaceuticals, Supply Chain Operations and Processes)	Enhanced Data Security and Fraud Prevention	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Health-Related Data, Supply Chain and Transaction Data)	Complexity of Implementation
29		et al						COVID-19				COVID-19	Inventory Management & Visibility (Data and Tracking Challenges, Logistics and Coordination Challenges)	Data and Communication Challenges	Supply Chain and Logistics Risks (Transportation and Distribution Disruptions, Demand and Supply Uncertainties, Operational and Coordination Challenges)	Source	In Vitro Diagnostics (IVD)	In Vitro Diagnostics (IVD)	Source				Strengthening Supply Chain Redundancy and Flexibility (Adaptability & Resilience, Supplier Diversification & Backup, Real-Time Data & Monitoring, Inventory Management & Buffer Stocks, Logistics & Distribution Flexibility)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Regulatory Constraints
29								eZTracker							Crisis and Urgent Disruption Management	Storage			Storage				Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Costs (Initial Investment Costs, Ongoing Operational and Maintenance Costs, Training and Adoption Costs, Security and Privacy Costs, Regulatory and Compliance Costs)
29								hyperledger fabric								Deliver			Deliver				Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Establishing Regulatory Compliance	Resistance to Change
29								pharma supply chain								Enable			Enable				Ensuring Efficient Resource Allocation (Pharmaceuticals, Data and Information Resources)		
29								traceability															Ensuring Inventory Optimization		
30	At the Epicenter of COVID-19–the Tragic Failure of the Global Supply Chain for Medical Supplies	Bhaskar, Sonu	2020	Frontiers in Public Health; Volume 8; Article number 562882	Article	Australia	109	blockchain	Comparative Analyses	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85097755560&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22AND+%22+supply+chain%22+AND+%22++Blockchain%22+AND+%22resilience%22%29&sessionSearchId=ba858a394cf3a41e671560b89f249057&relpos=1	COVID-19	Supply Chain Vulnerabilities (Supply Shortages and Unpredictability, Infrastructure Weaknesses)	Resource and Material Availability	Supply Chain and Logistics Risks (Transportation and Distribution Disruptions, Demand and Supply Uncertainties)	Plan	Medical Devices	Medical Devices	Plan	Blockchain	Improved Transparency and Traceability (of Medical Supplies, Pharmaceuticals, Medical Equipment)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization)	Protecting Sensitive Data with Encryption and Security Measures (Patient and Medical Records, Supply Chain and Transaction Data)	Privacy Concerns
30		et al						coronavirus disease 2019 (COVID-19)	Policy Analysis & Theoretical Framework				Inventory Management & Visibility (Demand and Inventory Management Challenges, Data and Tracking Challenges)	Regulatory and Compliance Issues (Transportation and Distribution Regulations, Regulatory and Compliance Issues)	Crisis and Urgent Disruption Management	Source	Medical Consumables	Medical Consumables	Source	Big Data and Analytics	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Enhancing Real-Time Monitoring and Decision-Making	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
30								global supply chain					Demand & Supply Management (Supply and Demand Issues, Coordination and Logistics)	Data and Communication Challenges	Data Security and Privacy Risks	Storage	Hospital Equipment	Hospital Equipment	Storage	Artificial Intelligence (AI)	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Developing Predictive and Risk Mitigation Models	Regulatory Constraints
30								governance								Deliver	Sterilization and Cleaning Products	Sterilization and Cleaning Products	Deliver	Cyber Security	Enhanced Data Security		Ensuring Efficient Resource Allocation (Medical Supplies, Pharmaceuticals, Healthcare Equipment and Infrastructure)	Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Legal Constraints
30								grand challenge								Enable			Enable				Ensuring Inventory Optimization	Establishing Regulatory Compliance	Costs (Initial Investment Costs, Scalability and Integration Costs, Security and Privacy Costs, Regulatory and Compliance Costs)
30								health policy																	Complexity of Implementation
30								open innovation																	Resistance to Change
30								personal protective equipments (PPEs)																	Policy Constraints

Paper n.	Title of the article	Author(s)	Publication date	Name of journal/conference, volume, issue, book, page numbers	Publication type	Country of affiliation of the first author	N. citations (Scopus)	Author Keywords	Methodology	Methodology type	Scopus Link	Identified cris*	Main logistic challenges	Main procurement challenges	Main risk management challenges	Supply chain process	Type of products	Type of products.	Supply chain process.	Digital technologies	Resilience improvements	Risk management improvements	Defined actions to improve resilience	Defined actions to improve risk management	Limits/Difficulties of integration of digital technologies
31	Blockchain adoption opportunities in healthcare sector	Althobaiti, Maha M	2020	International Journal of Engineering Trends and Technology; Volume 68; Issue 10; Pages 117 - 120	Article	Saudi Arabia	5	Application	Empirical Model Study	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85099927167&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22AND+%22+supply+chain%22+AND+%22++Blockchain%22+AND+%22resilience%22%29&sessionSearchId=ba858a394cf3a41e671560b89f249057&relpos=0							Pharmaceuticals	Plan	Blockchain	Improved Transparency and Traceability (Medical Data and Records, Pharmaceuticals, Financial and Transactional Data)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration, Implementing Digital Technologies and Automation, Enhancing Monitoring and Optimization)	Protecting Sensitive Data with Encryption and Security Measures (Patient and Medical Records, Personal and Sensitive Information, Health-Related Data, Supply Chain and Transaction Data)	Privacy Concerns
31								Blockchain	Comparative Analyses										Source		Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Supply Chain Transparency & Security, Real-Time Data & Monitoring, Risk Reduction & Fraud Prevention, Automation & Decision-Making)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
31								Healthcare	Literature Review										Storage		Enhanced Data Security		Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Regulatory Constraints
31																			Deliver				Building Collaborative and Transparent Ecosystems (Supply Chain and Healthcare Ecosystems)	Establishing Regulatory Compliance	Complexity of Implementation
31																			Enable						Costs (Initial Investment Costs, Scalability and Integration Costs, Security and Privacy Costs, Regulatory and Compliance Costs)
32	Leveraging Blockchain Technology to Establish a Transparent and Counterfeit-Resistant Pharmaceutical Supply Chain	Kumarswamy, Shruthi	2024	Journal Europeen des Systemes Automatises; Volume 57; Issue 5; Pages 1429 - 1443	Article	India	0	blockchain	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85207901370&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=4de5ca2354b3415ae003fe021a5f008a&relpos=6							Pharmaceuticals	Plan	Internet of Things (IoT)	Improved Transparency and Traceability (Pharmaceuticals, Supply Chain Operations and Processes)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Implementing Digital Technologies and Automation)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Supply Chain and Transaction Data, Health-Related Data)	Privacy Concerns
32		et al						coldchain distribution	Case Study										Source	Cloud Computing	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Adaptability & Resilience, Supplier Diversification & Backup, Real-Time Data & Monitoring, Inventory Management & Buffer Stocks, Logistics & Distribution Flexibility)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
32								ethereum	Empirical Research										Storage	Cyber Security	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Regulatory Constraints
32								healthcare	Conceptual Framework										Deliver	Blockchain	Enhanced Data Security		Building Collaborative and Transparent Ecosystems (Decentralized and Traceability Ecosystems, Collaborative and Data-Sharing Ecosystems)	Establishing Regulatory Compliance	Legal Constraints
32								pharmaceutical drug counterfeiting	Simulation Model Development										Enable					Developing Predictive and Risk Mitigation Models	Costs (Initial Investment Costs, Training and Adoption Costs, Ongoing Operational and Maintenance Costs)
32									Multi-Criteria Decision-Making Model																Complexity of Implementation
32									Comparative Analyses																Resistance to Change
32																									Policy Constraints
33	Blockchain Technology in Pharmaceutical Industry: A Review of Recent Research Articles on PubMed	Pareek, Varun	2024	Scripta Medica (Banja Luka); Volume 55; Issue 3; Pages 357 - 369	Article	India	0	Blockchain technology	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85199626980&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=4de5ca2354b3415ae003fe021a5f008a&relpos=8							Pharmaceuticals	Plan	Blockchain	Improved Transparency and Traceability (Pharmaceuticals, Supply Chain Operations and Processes)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Implementing Digital Technologies and Automation)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Health-Related Data, Other Sensitive Data)	Privacy Concerns
33		et al						Decentralised applications (dApps)	Conceptual Framework									Medical Consumables	Source	Cyber Security	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Logistics & Distribution Flexibility, Supplier Diversification & Backup, Inventory Management & Buffer Stocks)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
33								Drug supply chain	Case Study									In Vitro Diagnostics (IVD)	Storage	Big Data and Analytics	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Adopting Secure Coding Practices (Secure Coding Practicest)	Regulatory Constraints
33								Pharmaceutical industry	Empirical Research										Deliver	Cloud Computing	Enhanced Data Security		Building Collaborative and Transparent Ecosystems (Decentralized and Traceability Ecosystems, Collaborative and Data-Sharing Ecosystems)	Strengthening Data Security and Privacy	Legal Constraints
33								Smart Contracts	Comparative Analyses										Return	Cyber-Physical Systems (CPS)			Expanding Access and Building Infrastructure	Establishing Regulatory Compliance	Costs (Initial Investment Costs, Training and Adoption Costs, Ongoing Operational and Maintenance Costs)
33									Simulation Model Development										Enable						Complexity of Implementation
33									Prediction Model																Resistance to Change
33									Multi-Criteria Decision-Making Model																Policy Constraints
34	Healthcare Applications Using Blockchain With a Cloud-Assisted Decentralized Privacy-Preserving Framework	Deebak, Bakkiam David	2024	IEEE Transactions on Mobile Computing; Volume 23; Issue 5; Pages 5897 - 5916; Article number 10251641	Article	South Korea	6	Blockchain	Optimization Model Development	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85171748972&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=4de5ca2354b3415ae003fe021a5f008a&relpos=9							Pharmaceuticals	Plan	Blockchain	Improved Transparency and Traceability (of Supply Chain Operations and Processes, Movement and Tracking, Medical Data and Records, Financial and Transactional Data)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Implementing Digital Technologies and Automation, Strengthening Communication and Digital Collaboration)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Health-Related Data, Supply Chain and Transaction Data)	Privacy Concerns
34		et al						cloud	Simulation Model Development)									Medical Devices	Source	Cloud Computing	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Enhancing Real-Time Monitoring and Decision-Making	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
34								decentralized systems	Conceptual Framework									In Vitro Diagnostics (IVD)	Storage	Internet of Things (IoT)	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Building Collaborative and Transparent Ecosystems (Decentralized and Traceability Ecosystems, Collaborative and Data-Sharing Ecosystems)	Strengthening Data Security and Privacy	Regulatory Constraints
34								Internet of Things	Empirical Research										Deliver	Cyber Security	Enhanced Data Security		Ensuring Efficient Resource Allocation (Digital and Technological Resources)	Establishing Metrics and Standards (Performance and Efficiency Metrics, Compliance and Regulatory Standards; Data Integrity, Security, and Privacy Standards)	Legal Constraints
34								peer-to-peer communication											Return	Artificial Intelligence (AI)			Ensuring Inventory Optimization	Developing Predictive and Risk Mitigation Models	Costs (Initial Investment Costs, Training and Adoption Costs, Ongoing Operational and Maintenance Costs)
34								privacy											Enable	Cyber-Physical Systems (CPS)				Establishing Regulatory Compliance	Complexity of Implementation
34								service utilization																	Resistance to Change
34																									Policy Constraints
35	The impact of healthcare 4.0 technologies on healthcare supply chain performance: Extending the organizational information processing theory	Saha, Esha	2024	Technological Forecasting and Social Change; Volume 201; Article number 123256	Article	India	8	Healthcare 4.0 technologies	Empirical Model Study	Quantitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85184523140&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=4de5ca2354b3415ae003fe021a5f008a&relpos=10	Technological Cris*	Supply Chain Vulnerabilities (Fluctuations in Demand, Distribution and Transport Bottlenecks, Supply Shortages and Unpredictability, Storage and Infrastructure Limitations)	Resource and Material Availability	Supply Chain and Logistics Risks (Storage and Inventory Management Issues, Demand and Supply Uncertainties, Operational and Coordination Challenges, Regulatory and Compliance Risks)	Plan	Pharmaceuticals	Pharmaceuticals	Plan	Big Data and Analytics	Improved Transparency and Traceability (Supply Chain Operations and Processes)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Implementing Digital Technologies and Automation)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Health-Related Data, Supply Chain and Transaction Data)	Privacy Concerns
35		et al						Hospital supply chain processes	Comparative analysis				Demand & Supply Management (Supply and Demand Issues, Coordination and Logistics, Supply Shortages/Disruptions)	Regulatory and Compliance Issues (Transportation and Distribution Regulations, Regulatory and Compliance Issues)	Regulatory and Policy Challenges	Source	Medical Devices	Medical Devices	Source	Cloud Computing	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Logistics & Distribution Flexibility, Supplier Diversification & Backup, Inventory Management & Buffer Stocks)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
35								Organizational information processing theory (OIPT)	Structural Equation Modeling (SEM)				Inventory Management & Visibility (Demand and Inventory Management Challenges, Data and Tracking Challenges, Logistics and Coordination Challenges)	Data and Communication Challenges	Operational Risks and Digitalization (Cybersecurity and Data Risks, System and Technology Integration Risks, IT and Network Disruptions)	Storage	Medical Consumables	Medical Consumables	Storage	Artificial Intelligence (AI)	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Regulatory Constraints
35								Performance	Empirical Research						Crisis and Urgent Disruption Management	Deliver	In Vitro Diagnostics (IVD)	In Vitro Diagnostics, IVD	Deliver	Blockchain			Ensuring Inventory Optimization	Developing Predictive and Risk Mitigation Models	Legal Constraints
35									Survey							Return			Return	Cyber Security					Costs (Initial Investment Costs, Training and Adoption Costs, Ongoing Operational and Maintenance Costs)
35																Enable			Enable						Complexity of Implementation
35																									Resistance to Change
36	Supply chain risk factor assessment of Indian pharmaceutical industry for performance improvement	Sharma, Astha	2024	International Journal of Productivity and Performance Management; Volume 73; Issue 1; Pages 119 - 157	Article	India	8	Fuzzy synthetic evaluation	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85140378825&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28%22healthcare%22+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=4de5ca2354b3415ae003fe021a5f008a&relpos=13	Economic Cris*	Disruption in Transportation Networks	Supplier Challenges (Supply Chain Stability and Resilience Issues, Operational & Technological Challenges)	Supply Chain and Logistics Risks (Transportation and Distribution Disruptions , Storage and Inventory Management Issues, Demand and Supply Uncertainties)	Plan	Pharmaceuticals	Pharmaceuticals	Plan	Internet of Things (IoT)	Improved Transparency and Traceability (Pharmaceuticals, Supply Chain Operations and Processes)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Enhancing Monitoring and Optimization, Implementing Digital Technologies and Automation)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Supply Chain and Transaction Data, Health-Related Data)	Security Concerns
36		et al						Healthcare	Case Study			Geopolitical Cris*	Supply Chain Vulnerabilities (Fluctuations in Demand, Distribution and Transport Bottlenecks, Supply Chain Instability, Supply Shortages and Unpredictability)	Resource and Material Availability	Financial and Geopolitical Risks (Financial Risks, Geopolitical Risks)	Source			Source	Big Data and Analytics	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Logistics & Distribution Flexibility, Inventory Management & Buffer Stocks)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Regulatory Constraints
36								Pharmaceutical industry	Empirical Research			Health Security Cris*	Demand & Supply Management (Supply and Demand Issues, Coordination and Logistics, Supply Shortages/Disruptions)	Regulatory and Compliance Issues (Transportation and Distribution Regulations, Regulatory and Compliance Issues)	Crisis and Urgent Disruption Management	Storage			Storage	Blockchain	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Costs (Initial Investment Costs, Training and Adoption Costs, Ongoing Operational and Maintenance Costs)
36								Risk analysis	Fuzzy Synthetic Evaluation (FSE) Method			COVID-19	Infrastructure & Capacity Limitations (Resource and Material Availability, Data and Communication Challenges)	Cost and Economic Feasibility (Supply Chain Costs, Production and Procurement Costs)		Deliver			Deliver	Cloud Computing	Enhanced Data Security		Building Collaborative and Transparent Ecosystems (Decentralized and Traceability Ecosystems, Collaborative and Data-Sharing Ecosystems)	Developing Predictive and Risk Mitigation Models	Complexity of Implementation
36									Multi-Criteria Decision-Making Model							Return			Return	Cyber Security			Expanding Access and Building Infrastructure	Developing and Training the Workforce	Resistance to Change
36									Conceptual Framework							Enable			Enable				Ensuring Efficient Resource Allocation (Financial Resources, Human Resources, Digital and Technological Resources)	Building Collaborative and Transparent Ecosystems (Decentralized and Traceability Ecosystems, Collaborative and Data-Sharing Ecosystems)	
36																							Ensuring Inventory Optimization	Establishing Regulatory Compliance	

Paper n.	Title of the article	Author(s)	Publication date	Name of journal/conference, volume, issue, book, page numbers	Publication type	Country of affiliation of the first author	N. citations (Scopus)	Author Keywords	Methodology	Methodology type	Scopus Link	Identified cris*	Main logistic challenges	Main procurement challenges	Main risk management challenges	Supply chain process	Type of products
37	Blockchain based Health Records Management for Diabetes Patients: Real-World Applications	Sangwan, Poonam	2024	Proceedings - 2024 1st International Conference on Technological Innovations and Advance Computing, TIACOMP 2024; Pages 488 - 498	Conference Paper	India	0	Authorization	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85212155607&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28healthcare%22+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=4de5ca2354b3415ae003fe021a5f008a&relpos=18						
37		et al						Blockchain	Empirical Research								
37								Data Security	Simulation Model Development								
37								Healthcare	Conceptual Framework								
37								Medical records	Case Study								
37									Fuzzy Multi-Attribute Decision Making								
37									Comparative Analyses								
37									Cybersecurity and Risk Analysis								
38	Digitalization and the Medical Supply Chain Management: Systematic Literature Review and Bibliometric Analysis	Hiatt, Brian	2024	Operations and Supply Chain Management; Volume 17; Issue 3; Pages 128 - 140	Article	United States	0	blockchain	Systematic Literature Review (SLR)	Qualitative	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85209709563&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28healthcare+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=918d15426edeef376dee7b8ecb9b2485&relpos=20						
38		et al						digitalization	Bibliometric Analysis								
38								medical supply chain									
38								resiliency									
38								supply chain risk									
38								sustainability									
38																	
39	The Utilization of Blockchain for Data Security for the Chronic Pain Physician	Kruger, Jordan	2024	Current Pain and Headache Reports; Volume 28; Pages 1299-1305	Article	United States	0	Cybersecurity	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85207955762&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28healthcare+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=918d15426edeef376dee7b8ecb9b2485&relpos=25						
39		et al						Data privacy	Bibliometric Analysis								
39								Ethereum	Conceptual Framework								
39								Smart Contracts									
39								Transparency									
39																	
39																	
40	Designing and implementing a resilient immutability mechanism for enhanced supply chain management in E-healthcare systems	Singla, Deepak	2024	Frontiers in Sustainable Cities; Volume 6; Article number 1403809	Article	India	0	blockchain	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85201560786&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28healthcare+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=918d15426edeef376dee7b8ecb9b2485&relpos=28						
40		et al						collaborative environment	Empirical Research								
40								polygon near field communication	Mathematical Model Development								
40								Smart Contracts	Optimization Model Development								
40								supply chain	Simulation Model Development								
40									Conceptual Framework								
40									Comparative Analyses								
40									Empirical Model Study								
40									Citation Network Analysis								
40									Bibliometric Analysis								
41	Leveraging Deep Learning and Blockchain for Enhanced Transparency and Traceability in the Indian Herbal Product Supply Chain	Uniyal, Prateek	2024	2024 International Conference on Intelligent Systems for Cybersecurity, ISCS 2024	Conference Paper	India	1	blockchain	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85199301971&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28healthcare+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=918d15426edeef376dee7b8ecb9b2485&relpos=30						
41		et al						deep learning	Optimization Model Development								
41								image processing	Conceptual Framework								
41								medicinal plant supply chain	Simulation Model Development								
41								traceability	Empirical Research								
41									Comparative Analyses								
41																	
42	Enhancing Pharmaceutical Supply Chain Management: A Blockchain-Based Model	Ettaloui, Nehal	2024	2024 IEEE 15th International Colloquium of Logistics and Supply Chain Management, LOGISTIQUA 2024	Conference Paper	Morocco	1	Blockchain	Systematic Literature Review (SLR)	Mixed	https://www-scopus-com.ezproxy.biblio.polito.it/record/display.uri?eid=2-s2.0-85198102856&origin=resultslist&sort=plf-f&src=s&sot=b&sdt=b&s=TITLE-ABS-KEY%28healthcare+AND+%22+supply+chain%22+AND+%22+Blockchain%22+AND+%22risk%22%29&sessionSearchId=918d15426edeef376dee7b8ecb9b2485&relpos=31						
42		et al						Hyperledger Fabric	Conceptual Framework Development								
42								IPFS	Optimization Model Development								
42								Pharmacy	Simulation Model Development								
42								Suply Chain	Empirical Research								
42									Comparative Analyses								
42																	

Paper n.	Type of products.	Supply chain process.	Digital technologies	Resilience improvements	Risk management improvements	Defined actions to improve resilience	Defined actions to improve risk management	Limits/Difficulties of integration of digital technologie
37	Pharmaceuticals	Plan	Internet of Things (IoT)	Improved Transparency and Traceability (of Medical Data and Records)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Implementing Digital Technologies and Automation, Strengthening Communication and Digital Collaboration)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Health-Related Data, Supply Chain and Transaction Data)	Privacy Concerns
37	Medical Devices	Source	Big Data and Analytics	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Enhancing Real-Time Monitoring and Decision-Making	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
37		Storage	Blockchain	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Building Collaborative and Transparent Ecosystems (Decentralized and Traceability Ecosystems, Collaborative and Data-Sharing Ecosystems)	Strengthening Data Security and Privacy	Regulatory Constraints
37		Deliver	Cloud Computing	Enhanced Data Security		Expanding Access and Building Infrastructure	Developing Predictive and Risk Mitigation Models	Legal Constraints
37		Return	Cyber Security			Ensuring Efficient Resource Allocation (Medical Supplies, Data and Information Resources)	Establishing Regulatory Compliance	Costs (Initial Investment Costs, Training and Adoption Co Ongoing Operational and Maintenance Costs)
37		Enable						Complexity of Implementation
37								Resistance to Change
37								
38	Pharmaceuticals	Plan	Internet of Things (IoT)	Improved Transparency and Traceability (of Medical Supplies, Movement and Tracking)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Patient and Medical Records, Supply Chain and Transaction Data)	Privacy Concerns
38	Medical Devices	Source	Blockchain	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Logistics & Distribution Flexibility)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
38	Hospital Equipment	Storage	Artificial Intelligence (AI)	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Adopting Secure Coding Practices (Development and Maintenance secure software applications)	Regulatory Constraints
38	In Vitro Diagnostics (IVD)	Deliver	Cloud Computing			Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Strengthening Data Security and Privacy	Legal Constraints
38	Medical Consumables	Return	Cyber Security			Expanding Access and Building Infrastructure	Establishing Metrics and Standards (Performance and Efficiency Metrics, Quality and Reliability)	Costs (Initial Investment Costs, Ongoing Operational a Maintenance Costs, Training and Adoption Costs, Securit Privacy Costs, Regulatory and Compliance Costs)
38		Enable				Ensuring Efficient Resource Allocation (Medical Supplies, Healthcare Equipment and Infrastructure, Human Resources)	Developing Predictive and Risk Mitigation Models	Complexity of Implementation
38						Ensuring Inventory Optimization	Establishing Regulatory Compliance	Resistance to Change
39	Pharmaceuticals	Plan	Blockchain	Improved Transparency and Traceability (of Medical Data and Records)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Patient and Medical Records, Health-Related Data)	Privacy Concerns
39	Medical Devices	Source	Artificial Intelligence (AI)	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Supply Chain Transparency & Security)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
39	Medical Consumables	Storage	Cyber Security	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Regulatory Constraints
39	Hospital Equipment	Deliver	Internet of Things (IoT)	Enhanced Data Security		Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Developing Predictive and Risk Mitigation Models	Legal Constraints
39		Return				Ensuring Efficient Resource Allocation (Data and Information Resources)	Establishing Regulatory Compliance	Costs (Initial Investment Costs, Ongoing Operational a Maintenance Costs, Training and Adoption Costs, Securit Privacy Costs, Regulatory and Compliance Costs)
39		Enable				Ensuring Inventory Optimization		Complexity of Implementation
39								Resistance to Change
40	Pharmaceuticals	Plan	Blockchain	Improved Transparency and Traceability (Pharmaceuticals, Supply Chain Operations and Processes)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Health-Related Data, Supply Chain and Transaction Data)	Privacy Concerns
40		Source	Cyber Security	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Logistics & Distribution Flexibility, Supply Chain Transparency & Security)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
40		Storage	Artificial Intelligence (AI)	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Regulatory Constraints
40		Deliver	Internet of Things (IoT)	Enhanced Data Security		Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Establishing Metrics and Standards (Performance and Efficiency Metrics; Data Integrity, Security, and Privacy Standards)	Legal Constraints
40		Return	Cloud Computing			Ensuring Efficient Resource Allocation (Pharmaceuticals, Raw Materials and Supplies)	Developing Predictive and Risk Mitigation Models	Costs (Initial Investment Costs, Ongoing Operational a Maintenance Costs, Training and Adoption Costs, Securit Privacy Costs, Regulatory and Compliance Costs)
40		Enable				Ensuring Inventory Optimization	Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Complexity of Implementation
40							Establishing Regulatory Compliance	Resistance to Change
40								
40								
40								
41	Pharmaceuticals	Plan	Internet of Things (IoT)	Improved Transparency and Traceability (of Medical Equipment, Movement and Tracking)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration)	Protecting Sensitive Data with Encryption and Security Measures (Supply Chain and Transaction Data, Other Sensitive Data)	Privacy Concerns
41	In Vitro Diagnostics (IVD)	Source	Big Data and Analytics	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Supply Chain Transparency & Security)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
41	Laboratory Supplies	Storage	Cloud Computing	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Regulatory Constraints
41		Deliver	Artificial Intelligence (AI)	Enhanced Data Security		Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Establishing Metrics and Standards (Performance and Efficiency Metrics; Data Integrity, Security, and Privacy Standards)	Legal Constraints
41		Return	Blockchain			Expanding Access and Building Infrastructure	Developing Predictive and Risk Mitigation Models	Costs (Initial Investment Costs, Ongoing Operational a Maintenance Costs, Training and Adoption Costs, Securit Privacy Costs, Regulatory and Compliance Costs)
41		Enable				Ensuring Efficient Resource Allocation (Raw Materials and Supplies, Data and Information Resources)	Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Complexity of Implementation
41							Establishing Regulatory Compliance	Resistance to Change
42	Pharmaceuticals	Plan	Blockchain	Improved Transparency and Traceability (Pharmaceuticals, Supply Chain Operations and Processes)	Predictive and Proactive Risk Mitigation	Leveraging Digital Technologies for Resilience (by Strengthening Communication and Digital Collaboration)	Protecting Sensitive Data with Encryption and Security Measures (Personal and Sensitive Information, Health-Related Data, Supply Chain and Transaction Data)	Privacy Concerns
42		Source	Cyber Security	Better Inventory Management and Visibility	Enhanced Data Security and Fraud Prevention	Strengthening Supply Chain Redundancy and Flexibility (Supplier Diversification & Backup, Logistics & Distribution Flexibility, Supply Chain Transparency & Security)	Strictly Controlling Access to Data and Prevent Cyber-Attacks	Security Concerns
42		Storage	Cloud Computing	Optimization of Logistics and Operations (Inventory Management, Distribution Network Design, Order Processing, Cold Chain Management, Supplier Reliability)	Compliance and Environmental Risk Management (Regulatory and Sustainability Improvement)	Enhancing Real-Time Monitoring and Decision-Making	Strengthening Data Security and Privacy	Regulatory Constraints
42		Deliver	Artificial Intelligence (AI)	Enhanced Data Security		Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Establishing Metrics and Standards (Performance and Efficiency Metrics; Data Integrity, Security, and Privacy Standards)	Legal Constraints
42		Return				Ensuring Efficient Resource Allocation (Pharmaceuticals, Raw Materials and Supplies)	Developing Predictive and Risk Mitigation Models	Costs (Initial Investment Costs, Ongoing Operational a Maintenance Costs, Training and Adoption Costs, Securit Privacy Costs, Regulatory and Compliance Costs)
42		Enable				Ensuring Inventory Optimization	Building Collaborative and Transparent Ecosystems (Collaborative and Data-Sharing Ecosystems)	Complexity of Implementation
42							Establishing Regulatory Compliance	Resistance to Change