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Digitalization in Biomedical Supply Chain: A Systematic Literature Review and Future Directions

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Abstract

This paper presents the findings of a systematic literature review focused on digital transformation within biomedical supply chains (BMSCs). The review analyzed peer-reviewed articles published to identify enablers and barriers, classify technologies, and highlight trends across literature. Using a function-oriented framework based on the SCOR-DS model, the study categorizes blockchain, smart contracts, AI/ML etc as digital technologies according to their contributions across planning, sourcing, manufacturing, delivery, and returns. The findings highlight that while significant attention has been given to technologies supporting traceability, real-time monitoring, and automation, limited studies explore the integration of underrepresented tools such as digital twins and 3D printing. The research identifies critical enablers such as enhanced visibility and process optimization and barriers including cybersecurity risks, high implementation costs, and interoperability issues. The review contributes a structured classification and graphical synthesis of digital technologies in BMSCs, filling a gap in current literature that often overlooks function-based integration. These findings establish a foundation for future research into interdependent digital factors influencing supply chain performance, offering practical insights to support the design of more efficient and technology-driven biomedical supply chains.

Keywords
Supply Chain, Biomedical, Digital Technologies, Enablers, Barriers.

1. Introduction

In the globalized, data-driven economy, Supply Chain Management (SCM) is recognized as a vital strategic function that directly influences operational efficiency, cost-effectiveness, customer satisfaction, and competitiveness (Min et al., 2019). Traditionally, SCM involves systematic coordination of activities such as sourcing, manufacturing, warehousing, transportation, and distribution. As businesses face increasing complexity due to globalization, customization demands, shorter product life cycles, and disruptions such as pandemics or geopolitical instabilities, there has been a growing push to make supply chains more resilient, responsive, and intelligent. This evolution is being powered by the adoption of digital technologies, giving rise to what is now termed as the digital supply chain (Ivanov et al., 2022).

A critical, yet less explored segment of this transformation lies within the Biomedical Supply Chain (BMSC). The BMSC encompasses the end-to-end flow of highly sensitive medical goods, including pharmaceuticals, vaccines, surgical equipment, diagnostic kits, prosthetics, and biologics (Shah et al., 2024). Unlike general supply chains, the biomedical sector deals with life-critical products, meaning that failures in quality, timing, or traceability can result in serious consequences for patient health and safety. This sector is governed by complex regulatory frameworks such as the U.S. FDA, EU MDR, ISO standards, and local health ministries, all of which demand rigorous documentation, traceability, and risk management (Clauson et al., 2018a).

In such a high-stakes environment, digitalization of the biomedical supply chain presents a unique opportunity to enhance its efficiency, responsiveness, and safety. It has emerged as a key enabler in addressing these issues. However, due to the sector's specificity and complexity, not all digital technologies can be adopted without careful customization, validation, and regulatory approval (Mackey & Nayyar, 2017).

In this context, enablers and barriers are important in determining the success or failure respectively of digital transformation of supply chain. Enablers facilitate or accelerate the adoption and effective implementation of digital technologies. On the other hand, barriers are the obstacles that limit or slow down digital transformation.

1.1 Objective

While numerous studies have explored digitalization in supply chains in general, there is a significant research gap when it comes to their application in the biomedical context. Existing literature often focuses on individual technologies in isolation or examines use cases without considering the comprehensive ecosystem of enablers and barriers that influence their real-world applicability in healthcare supply chains.

Given the increasing importance of resilient biomedical logistics highlighted most recently by global pandemic, for example the COVID-19, there is an acute need for a systematic, consolidated review of how digital technologies are impacting the BMSC (Saeed et al., 2022). Furthermore, it is essential to understand which factors facilitate or hinder their adoption so that policy makers, hospital administrators, supply chain managers, and technology providers can make informed decisions.

Given this context, the following research questions arise:

1. Which digital technologies are most widely used in biomedical supply chain management?
2. What are the major challenges and benefits involved with implementation of digital technologies in the biomedical supply chain?

In light of these questions, the aim of this study is to systematically review the existing literature to identify, classify, and assess the use of digital technologies in BMSC, evaluate their associated enablers and barriers, and Map technologies to supply chain functions using the SCOR-DS (Supply Chain Operations Reference – Digital Standard) model. The study also seeks to highlight research gaps and provide guidance for future academic investigation and practical implementation in healthcare systems.

The organization of this article continues in the subsequent sections, as described in Figure 1, starting with Section 1 which introduces the biomedical supply chain, provides an overview of digital technologies, outlines their functions within BMSC, and discusses the key enablers and barriers to their adoption. Then Section 2 explains the review methodology in two phases. The results and discussion, including the classification of digital technologies across BMSC and graphical representations of benefits and challenges are presented in section 3 and finally, Section 4 concludes the research by summarizing key insights and proposing future research directions.

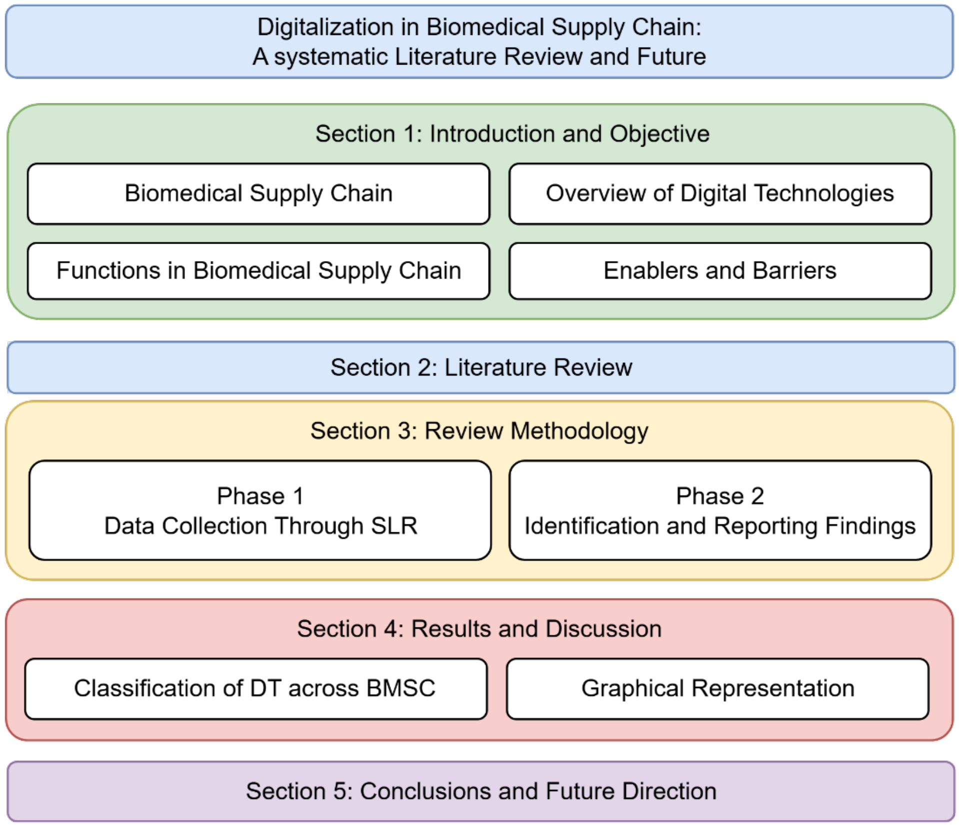

Figure 1. Outline of this paper

2. Literature Review

A growing body of literature emphasizes that in a digital supply chain, Artificial Intelligence (AI), Internet of Things (IoT), blockchain, cloud computing, and big data analytics are technologies used to automate processes, enhance real-time tracking, and support predictive decision-making. These advancements have already demonstrated significant benefits across multiple industries from retail and manufacturing to aerospace and automotive where digitalization has reduced inefficiencies, improved visibility, and supported data-driven strategies. Many digital technologies are being widely used in BMSC, whose benefits and challenges are discussed in Table 1.

Blockchain enhances transparency, ensures data immutability, and secures the traceability of products across the supply chain, helping to combat counterfeit drugs and enhance patient safety (Di Pierro, 2017). **Smart Contracts** (Xu et al., 2021), built on blockchain platforms, automate procurement, compliance, and payment processes in real time, reducing administrative burdens and operational delays. **Artificial Intelligence (AI)** and **Machine Learning (ML)** (Younis et al., 2022) improve supply and demand forecasting, enable adaptive logistics during emergencies, and support personalized medicine logistics by analyzing large patient-specific data sets. **Internet of Things (IoT)** (De Vass et al., 2021) devices such as temperature sensors and GPS trackers enable real-time monitoring of conditions during the transportation and storage of temperature-sensitive items like vaccines or blood products. **Cloud Computing** (Cao et al., 2017) allows for centralized, scalable data storage and access, facilitating coordination among multiple supply chain stakeholders across geographies. **Big Data Analytics** (Kache & Seuring, 2017) supports strategic planning and inventory optimization by uncovering patterns in large and complex datasets, thus minimizing shortages or overstocking. **3D Printing/Additive Manufacturing** allows for decentralized, on-demand production of medical tools, prosthetics, and implants, which can significantly reduce lead times and improve access in remote areas (Kunovjanek et al., 2022). **Digital Twin Technology** creates virtual copies from actual physical supply chains to simulate disruptions, optimize planning, and test interventions in a risk-free environment (Srai et al., 2019). **Radio**

Frequency Identification (RFID) and barcode scanning systems improve inventory accuracy, support efficient asset tracking, and reduce delivery errors (Raza, 2022).

Table 1. Overview of Digital Technologies in Biomedical Supply Chain Management

Digital Technology	Enablers	Barriers	References
Blockchain	Improves traceability, combats counterfeit drugs, secures data sharing in biomedical logistics	Scalability, energy use, lack of real-world implementations, interoperability issues	(Clauson et al., 2018b; Dhingra et al., 2024; Fiore et al., 2023)
Smart Contracts	Automates procurement and verification processes in medical supply chains	Dependence on blockchain platforms, legal and standardization issues	(Beaulieu et al., 2024; Hiatt et al., 2024)
Artificial Intelligence (AI)	Enhances diagnostics, supply-demand matching, and operational decision-making in healthcare	Needs extensive healthcare data, model transparency and trustworthiness are limited	(Beaulieu et al., 2024; Furstenau et al., 2022)
Machine Learning (ML)	Improves demand prediction and patient-specific treatment logistics	Bias in prediction, need for large biomedical datasets	(Chowdhury et al., 2024; Man et al., 2024)
Internet of Things (IoT)	Enables real-time monitoring of temperature-sensitive biomedical shipments	Data privacy risks, integration issues with legacy healthcare systems	(Amin et al., 2021; Heeres et al., 2023)
Cloud Computing	Provides scalable access to supply chain data, supports remote inventory management	Security threats, infrastructure dependency, latency in real-time data sync	(Tie et al., 2022)
Big Data Analytics	Helps analyze usage patterns, predict shortages, and plan biomedical supply	Data accuracy, integration complexity, privacy concerns	(Amin et al., 2021)
3D Printing / Additive Manufacturing	Enables patient-specific implants and decentralized production near point-of-care	High cost, regulatory challenges, limited material options for biocompatibility	(Chowdhury et al., 2024; Emelogu et al., 2016)
Digital Twins	Simulates and monitors supply chain behavior to optimize performance and maintenance	Complex modeling, high setup cost, requires detailed real-time data	(Sharma et al., 2025; Sheng & Chen, 2022)
RFID & Barcode Scanning	Tracks medical inventory and ensures correct product delivery	Initial infrastructure cost, need for widespread tagging compliance	(Ahmed et al., 2021; Borelli et al., 2015; Kumar et al., 2009; Yee-Loong Chong et al., 2015)

These technologies, while powerful, come with a dual nature and they can act as both enablers and barriers in the context of digital transformation (Oubrahim & Sefiani, 2023). Enablers include factors such as top management support, increasing investment in healthcare digital infrastructure, rising regulatory incentives for traceability and transparency, and growing awareness among supply chain actors about the benefits of digitalization. These factors promote the successful adoption and integration of digital tools in biomedical logistics (Gebhardt et al., 2022).

The implementation of digital technologies in BMSC is inhibited by a number of disadvantages/barriers. These include high implementation and maintenance costs, lack of interoperability with legacy systems, fragmented and uncoordinated supply chain networks, cybersecurity and patient data privacy concerns, shortage of digitally skilled healthcare professionals, and regulatory hurdles that delay the adoption of emerging technologies. Moreover, the need for rigorous validation and the ethical implications of automated decision-making in healthcare settings add layers of complexity that do not exist in general supply chains (Thirumal et al., 2024).

3. Review Methodology

This work is centered on performing a systematic literature review (SLR) of published research articles to derive an unbiased summary of the findings consisting of two steps to identify key enablers (positive factors) and barriers (negative factors) in biomedical supply chain management, due to integration and implementation of digital technologies across biomedical supply chain functions. SLR is useful for this study as it helps organize and combine results from different researches in a structured way which allows the identification of ideas and findings that appear frequently, understanding the concepts or frameworks used in the field, and most importantly, gaps in the existing literature that have not been fully studied or understood yet, which future research can address (Carrera-Rivera et al., 2022). By reviewing published research works, SLR helps build an in-depth understanding of how digital technologies impact BMSC performance and how they fit into and support with the supply chain functions (Randles & Finnegan, 2023). The SLR process in this study has two key phases which are mentioned in Figure 2: (1) Phase one involves the formation of clear research questions and objectives, which is then followed by a structured literature review to identify relevant digital technologies used in the biomedical supply chain and (2) In second phase, the collected data is then analyzed to find out which digital technologies are used most often along with their benefits and challenges in the biomedical supply chain (Sultana et al., 2024).

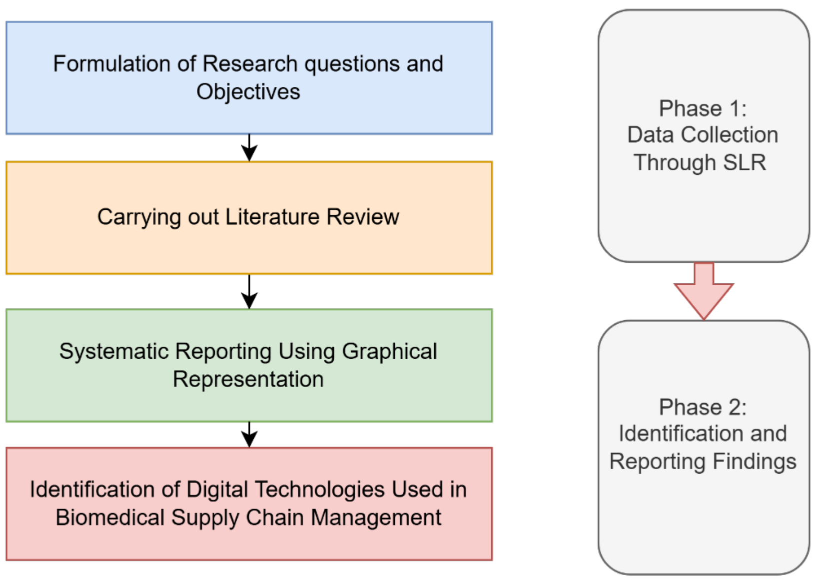

Figure 2. Review Methodology

3.1 Phase One: Data Collection Through Systematic Literature Review:

3.1.1 Selection of Database

In this study, the systematic Literature Review (SLR) used five major academic databases to find and collect relevant articles. These databases are Scopus, Web of Science, Science Direct, IEEE and Google Scholar. These include a wide range of reputable and trusted sources including articles indexed in Springer, Elsevier (ScienceDirect), Taylor & Francis, Emerald, and other well-known publishers. Its intensive indexing enabled the finding of key research papers on how digital technologies are changing supply chain management, especially within the biomedical sector.

3.1.2 Definition of Search Terms

Search terms were selected to identify enablers and barriers related to digitalization in biomedical supply chain management. The search strategy was formed by using two groups of keywords to make the search more focused and accurate.

The first group used search terms like “Biomedical”, “Digitalization”, “Supply Chain”, “Health”, “logistic”, “Enablers”, “Barriers”, and “Digital technology”
The second group focused more on specific technologies such as “Medical Equipment”, “HealthCare”, “IoT”, “Block Chain" and “AI”.

The term “Biomedical” focused the search on medical equipment and technologies used in clinical supply chains. “Digitalization” identified studies about the integration of technologies which are IoT, blockchain, and AI into supply chains. “Supply Chain” ensured relevant studies on logistics, distribution, and system efficiency. This search strategy helped in finding more accurate and relevant papers, allowing for a wider range of how digital technologies act as both drivers and barriers in the biomedical supply chain.

3.1.3 Article Selection Process:

- **Inclusion and Exclusion Criteria**
  To make the review more focused, reliable and high quality, inclusion and exclusion criteria were applied. The inclusion criteria focused on the selection of articles published between 2015 and 2025. This decade of timeframe was chosen because digitalization has only recently started being widely used in biomedical and healthcare supply chain. Peer-reviewed journal articles, conference proceedings and review papers were selected. This ensures the information and data is credible and well researched.

  Exclusion criteria were used to filter out articles that did not focus on digitalization in biomedical supply chains. Studies lacking clear discussions on enablers, barriers, or supply chain strategy were excluded. Additionally, grey literature including white papers, opinion pieces, non-peer-reviewed reports, or any publications falling outside the 2015–2025 window were filtered out.
- **Search Overview**
  The search was conducted across five major academic and scholarly databases: Google Scholar, Scopus, IEEE, Web of Science, and ScienceDirect. Using well-defined keyword combinations relevant to digital technologies in biomedical supply chains, initially a total of 365 articles were identified.

- **First Filtration**
  In the first stage of screening, the titles, abstracts, and keywords of all identified articles were reviewed. This helped eliminate irrelevant entries and reduced the pool to 320 articles that showed potential alignment with the topic.

- **Second Filtration (Abstract and Conclusion Screening)**
  Articles were then checked for duplication, resulting in the removal of 37 articles, bringing the number to 283 unique entries. From these, additional articles were excluded based on abstract and content irrelevance primarily because they did not focus on digital technologies, enablers, barriers, or biomedical supply chain strategies.

- **Final Selection**
  After the abstract screening, 32 full-text articles were reviewed for methodological quality, clarity, and relevance. Following this, 30 high-quality and domain-specific articles were selected for inclusion. These papers provided robust evidence and formed the analytical foundation for the thematic classification and framework development.

- **Rationale**
  The finalized selection offers a solid base of evidence for analyzing how digital technologies help in the biomedical supply chain and identifying barriers that make implementation difficult, supporting directly to the study’s research objectives and main goals. Additionally, the selected literature was analyzed according to the specific functions of Biomedical Supply Chain (BMSC). This function-specific approach helped us to understand how each digital technology is used in each operational stage of the supply chain, adding more depth to the study’s analysis and practical applicability in real world settings (Figure 3).

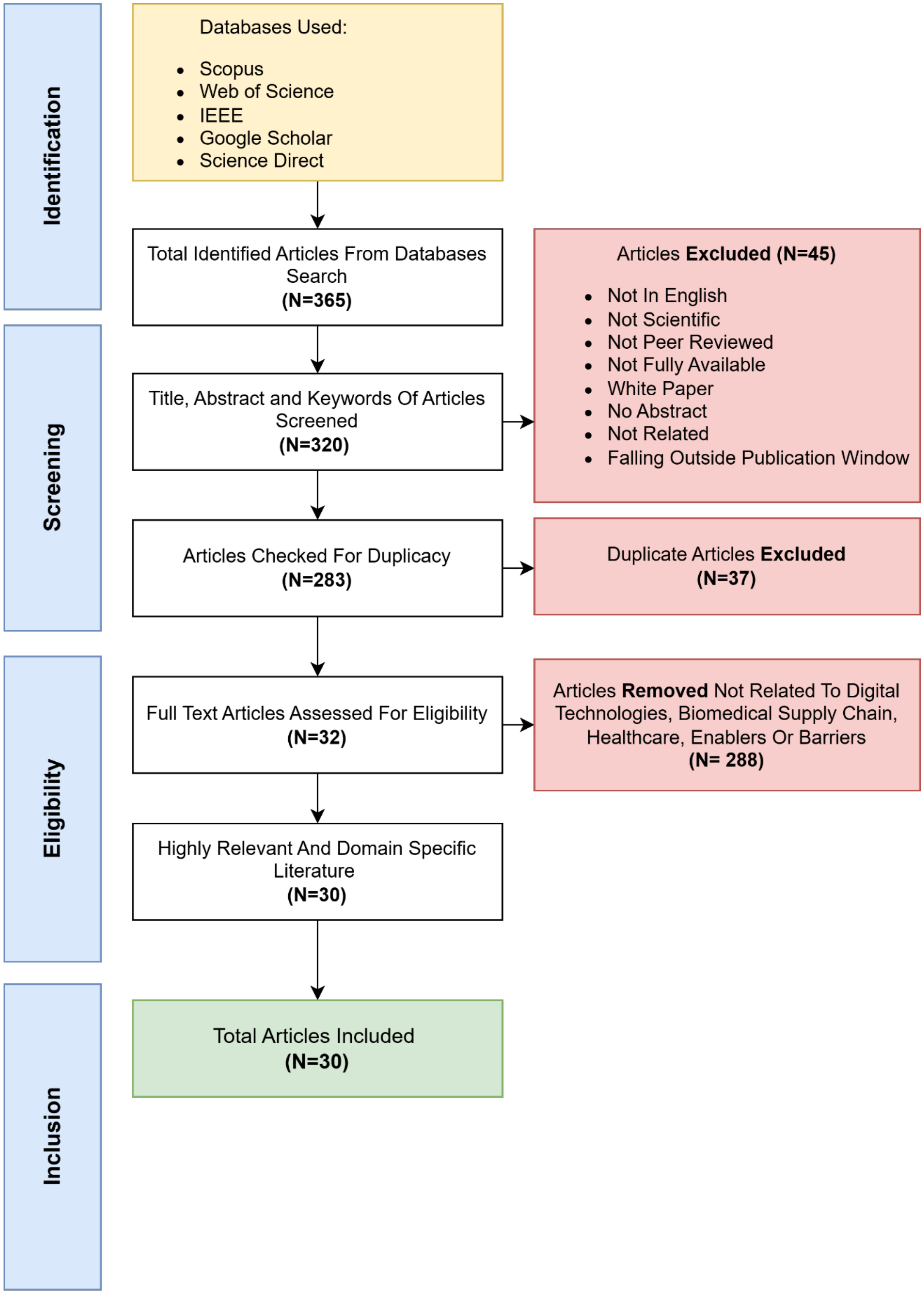

Figure 3. Structure of the systematic literature review process conducted.

3.2 Phase Two: Identification and Reporting Findings:

In the second phase of SLR, the selected studies were analyzed to extract and organize data related to the use of digital technologies in different functions of the biomedical supply chain. A method known as qualitative synthesis approach was used to categorize and group Digital Technologies (DTs), including blockchain, smart contracts, artificial intelligence/machine learning (AI/ML), cloud computing, big data analytics, Internet of Things (IoT), radio frequency identification (RFID), 3D printing/additive manufacturing, and digital twin. These relevant technologies were matched to specific supply chain functions used in biomedical based on their practical applications. A detailed table was developed including all the identified technologies along with its associated functions.

4. Results and Discussion

The digital technologies and biomedical supply chain have been integrated to work together as part of a larger system. Instead of treating each technology separately, this discussion focuses on how these functions within the wider system of biomedical supply chain and how they enhance performance, especially under unpredictable conditions such as global health crises like COVID (Ahmad et al., 2021).

The usage of blockchain and smart contracts in orchestrating, ordering, and returning processes was observed. These technologies provide a decentralized infrastructure that ensures the integrity of transactions and automates compliance. Within the orchestrate function, blockchain builds trust across stakeholders by maintaining immutable records, while smart contracts minimize manual oversight by executing pre-defined agreements (Epiphaniou et al., 2020). In return operations, they improve the efficiency of recall and reverse logistics processes. In the planning function, the consistent use of AI, machine learning, and big data analytics reflects a broader shift toward predictive supply chain management. These tools help organizations anticipate demand fluctuations, allocate resources more effectively, and minimize waste. Studies emphasized that during disruptions, organizations with AI-enabled planning systems were more adaptive and less prone to stockouts (Singh, 2023). Digital twins enhance this capability further by allowing supply chains to be tested in virtual environments, identifying weaknesses before they impact operations. The ordering and sourcing functions also benefited significantly from digitalization (Sheng & Chen, 2022). Blockchain's role in ensuring traceable, verifiable procurement was matched by the adoption of IoT and RFID in sourcing sensitive biomedical materials. These technologies made it possible to track the condition and location of goods in actual real time, reducing risks associated with expired, tampered, or mishandled products. RFID, in particular, emerged as a key solution for inventory tracking and cold-chain compliance, as seen in vaccine distribution (Yee-Loong Chong et al., 2015). Under the transform function, additive manufacturing (3D printing) stood out for its ability to decentralize production and enable on-demand fabrication of medical devices (Kunovjanek et al., 2022). Combined with AI for optimizing production workflows and smart contracts for automating approvals, the result is a more responsive and customizable supply chain structure. Return functions and fulfillment were improved by introducing cloud computing, blockchain, and sensor-based technologies like RFID and IoT. These tools provided greater visibility real time over delivery networks and improved the tracking of movements of products. Now, systems can automatically accept returns or trigger recalls without manual effort, which helped healthcare providers minimize errors and respond faster to newer issues (Cao et al., 2017).

The result of this study reveals that the implementation of digitalization in the biomedical supply chain isn’t a temporary change, but a fundamental shift in how biomedical supply chain is managed. These technologies are integrated into core functions. This kind of interconnected system makes the entire supply chain smarter, faster, and more secure. The study organized these findings using the SCOR-DS model, a well-known framework that maps out supply chain functions in Table 2.

Table 2. SCOR DS-Based Classification of Digital Technologies across Biomedical Supply Chain Functions

	Digital Technologies									
Functions	Block Chain	Smart Contracts	AI/ML	Cloud Computing	Big Data Analytics	IoT	RFID	3D Printing / Additive Manufacturing	Digital Twin	Ref
Orchestrate	✓	✓		✓						(Dhingra et al., 2024; Fiore et al., 2023; Tie et al., 2022)
Plan			✓	✓	✓				✓	(Beaulieu et al., 2024; Sheng & Chen, 2022)
Order	✓	✓		✓						(Clauson et al., 2018b; Khatoon, 2020)
Source	✓					✓	✓			(Ahmed et al., 2021; Heeres et al., 2023; Kumar et al., 2009)
Transform			✓			✓		✓	✓	(Chowdhury et al., 2024; Emelogu et al., 2016; Sharma et al., 2025; Sheng & Chen, 2022)
Fulfill	✓			✓		✓	✓			(Ahmed et al., 2021; Fiore et al., 2023; Heeres et al., 2023; Tie et al., 2022)
Return	✓			✓		✓				(Clauson et al., 2018b; Dhingra et al., 2024)

4.1 Graphical Results

The graphical results of this study are crucial for understanding the publication trends and technological emphasis in the digitalization of Biomedical Supply Chains (BMSC). Figure 4 illustrates the temporal distribution of research articles from 2015 to 2025, highlighting how scholarly attention on the digitalization of biomedical supply chains has significantly increased in recent years. Notably, there is a steep rise in published work from 2020 onwards, which aligns with the global impact of the COVID-19 pandemic that exposed vulnerabilities in healthcare logistics and accelerated digital transformation across medical systems. The year 2023 showed the highest number of publications, suggesting a growing academic and industry interest in enhancing BMSC resilience through digital innovation.

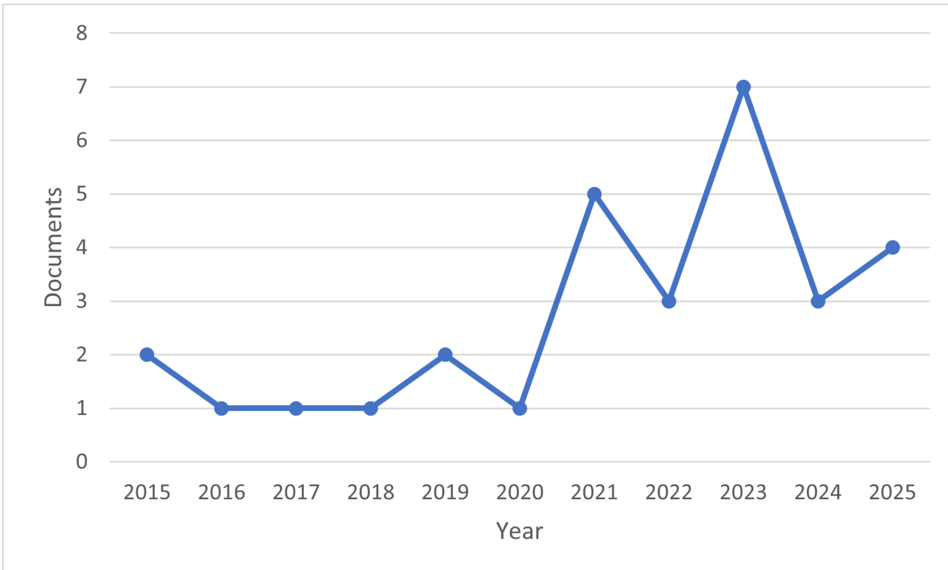

Figure 4. Articles by year

Figure 5 categorizes the selected articles based on the digital technologies they focus on. The results show that artificial intelligence and machine learning (AI/ML) accounts for the largest share, representing 20% of the total literature. This dominance reflects technology's growing importance in enabling predictive analytics, demand forecasting, and intelligent decision support systems for biomedical logistics and healthcare operations. It is followed by blockchain technology with 15%, which continues to gain significant attention for its ability to ensure transparency, traceability, and security across medical product lifecycles. Other technologies such as Internet of Things (IoT), cloud computing, and big data analytics, each ranging between 11% to 13%, demonstrate their value in enhancing real-time visibility, interoperability, and data-driven decision-making throughout the supply chain.

Some newer technologies like digital twins, RFID, and 3D printing showed up less often in research articles, indicating either they are still new in the biomedical domain, or they haven't been studied much to date. This gap opens opportunities for future research. Overall, these figures underscore both the evolution and current landscape of digital adoption in BMSC, while also reflecting how events like COVID have pushed technological implementation in this field. Smart contracts, representing 5%, are in their early research stages but show potential for automating transactions and regulatory compliance.

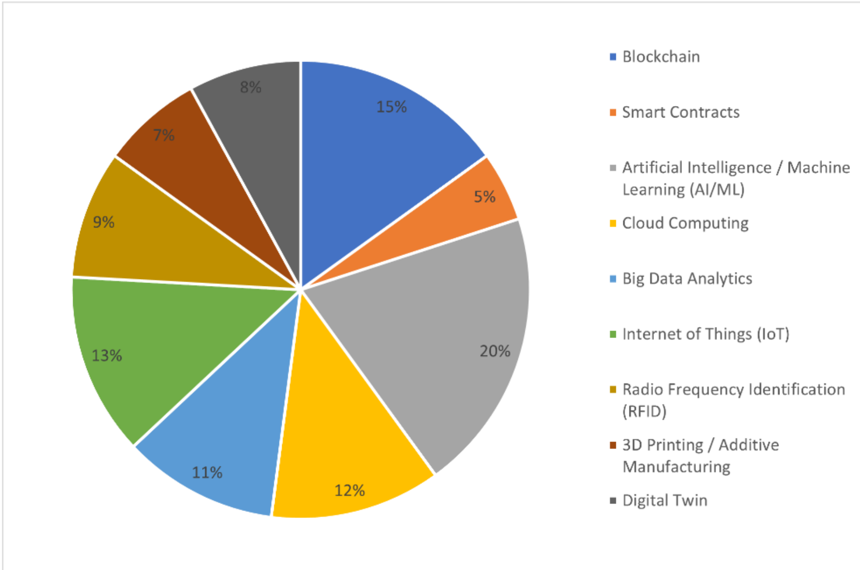

Figure 5. Articles by Digital Technologies in Biomedical Supply Chain

4.2 Validation

This paper's validation followed a structured and detailed process, a systematic approach to ensure the unbiased research results and its reliability. This paper was written by a graduate student under the guidance of a scholarly and knowledgeable professor, who gave feedback and oversight during important parts of the review, which improved the paper's accuracy and depth. The researchers used a carefully planned search across several trusted academic databases. They followed clear inclusion and exclusion criteria to make sure only the most accurate, highly relevant and high-quality articles were selected and included. Each chosen article was analyzed for its relevance, quality, and usefulness to the research topic. This helped strengthen the credibility of the results. The validation process of the paper was conducted by drawing on reputable research journals' peer-review processes and accurate quality checks to ensure that the research was valid (Latif, 2024).

5. Conclusion

The research goals for this study were reached by following a SLR to identify, classify, and evaluate digital technologies and tools utilized in the Biomedical Supply Chain (BMSC) domain, as well as observing the key advantages and disadvantages in their utilization.

This study provides a structured and comprehensive review of how these technologies relate with specific supply chain processes using a supply chain function mapping approach based on the SCOR-DS framework. The review has graphical results as well that show patterns in technology use and research over time which provides a complete picture of the digitalization in healthcare logistics. This research's important work is its function-oriented classification, which does not include individual discussions of technologies but looks at the technologies as part of a connected system throughout the supply chain. Using this approach offers practical insights for stakeholders wanting to increase transparency, efficiency, and responsiveness in biomedical logistics.

5.1 Future Direction

Although this study was focused on finding, identifying and categorizing enablers and barriers of digital tools of biomedical supply chain, future work can explore how these enablers and barriers are connected by investigating the linkages and interdependence between them. By understanding how certain barriers cause recurrent issues or how specific enablers drive system-level improvements can provide essential information for strategic planning. Such an approach could also help to guide the creation of focused interventions to boost technology adoption and overall supply chain performance. As healthcare supply chains become more complex, understanding these deeper dynamics will be critical for allowing long-term reform.

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