

Pharmaceutical logistics system development through the stages of industrial revolutions: A bibliometric review

Phát triển hệ thống logistics dược phẩm qua các giai đoạn cách mạng công nghiệp:
Đánh giá thư mục học

Nguyen Thi Mai Dieu^{a*}, Regina Kalangeg Puma-at^a, Bui Duc Anh^a
Nguyễn Thị Mai Diệu^{a*}, Regina Kalangeg Puma-at^a, Bùi Đức Anh^a

^aSouthStar Management Institute (SMi), Duy Tan University, Da Nang, 550000, Viet Nam

^aViện Quản lý Nam Khuê, Đại học Duy Tân, Đà Nẵng, Việt Nam

(Date of receiving article: 11/01/2025, date of completion of review: 20/03/2025, date of acceptance for posting: 11/04/2025)

Abstract

Introduction: The pharmaceutical logistics system plays a crucial role in ensuring the timely delivery of medications to patients, forming a complex network involving multiple stakeholders. This field has significantly developed due to technological innovations driven by industrial revolutions. As modern technologies such as Industry 4.0, digital transformation, and artificial intelligence (AI) reshape supply chains, their impact on pharmaceutical logistics becomes increasingly important.

Research objectives: This study provides a quantitative overview of the development of pharmaceutical logistics systems through the different stages of industrial revolutions. The goal is to assess how industrial revolutions have influenced the development of pharmaceutical logistics, focusing on the integration of advanced technologies and systems into pharmaceutical supply chain management strategies.

Subjects and methods: This study employs a bibliometric analysis method, utilizing data from 113 academic articles collected from the Scopus, Web of Science, and PubMed databases. The analysis was conducted using the Bibliometrix package in R, examining key metrics such as influential journals, citation trends, and major research keywords. Visualization tools, such as keyword co-occurrence networks, keyword frequency maps, and co-occurrence maps, were used to provide a comprehensive view of the development of pharmaceutical logistics research across industrial revolution stages.

Research findings: The data reveals a significant increase in research in the field of pharmaceutical logistics, particularly from 2016 onwards, with a sharp rise after 2019, likely due to the impact of the COVID-19 pandemic. Key technologies that emerged in the research include blockchain, Internet of Things (IoT), artificial intelligence (AI), and automation, which are revolutionizing pharmaceutical supply chains. The most discussed topics in the research include pharmaceutical supply chains, blockchain, and IoT, reflecting the growing integration of technology in securing and optimizing pharmaceutical distribution systems. Furthermore, AI, automation, and digital transformation are identified as key trends in pharmaceutical logistics.

Conclusion: The findings emphasize the significant impact of technological integration in the development of modern pharmaceutical logistics. Technologies such as blockchain, IoT, and AI are enhancing transparency, efficiency, and resilience in supply chains. Future research should focus on optimizing AI-driven decision-making systems, exploring sustainability in pharmaceutical supply chains, and addressing challenges related to drug security and counterfeit prevention.

Keywords: Pharmaceutical logistics system development; industrial revolutions; bibliometric analysis; blockchain; Internet of Things (IoT); artificial intelligence; supply chain management; digital transformation.

Tóm tắt

Giới thiệu: Hệ thống logistics được phẩm đóng vai trò then chốt trong việc đảm bảo phân phối thuốc kịp thời đến bệnh nhân, tạo thành một mạng lưới phức tạp với sự tham gia của nhiều bên. Lĩnh vực này đã phát triển mạnh mẽ nhờ vào những đổi mới công nghệ mang lại từ các cuộc cách mạng công nghiệp. Khi các công nghệ hiện đại như Công nghiệp 4.0, chuyên đổi số và trí tuệ nhân tạo (AI) định hình lại chuỗi cung ứng, tác động của chúng đến logistics được phẩm ngày càng quan trọng.

Mục tiêu nghiên cứu: Nghiên cứu này cung cấp một cái nhìn tổng quan định lượng về sự phát triển của hệ thống logistics được phẩm thông qua các giai đoạn khác nhau của các cuộc cách mạng công nghiệp. Mục tiêu là đánh giá sự ảnh hưởng của các cuộc cách mạng công nghiệp đến phát triển logistics được phẩm, tập trung vào việc tích hợp các công nghệ và hệ thống tiên tiến trong các chiến lược quản lý chuỗi cung ứng được phẩm.

Đối tượng và Phương pháp: Nghiên cứu này áp dụng phương pháp phân tích thư mục (bibliometric analysis), sử dụng dữ liệu từ 113 bài báo học thuật được thu thập từ các cơ sở dữ liệu Scopus, Web of Science và PubMed. Phân tích được thực hiện với sự hỗ trợ của gói phần mềm Bibliometrix trong R, nghiên cứu các chỉ số quan trọng như tạp chí có ảnh hưởng, xu hướng trích dẫn, và các từ khóa nghiên cứu chủ yếu. Các công cụ trực quan hóa như mạng lưới đồng xuất hiện từ khóa, bản đồ tần suất từ khóa và các bản đồ đồng xuất hiện được sử dụng để cung cấp cái nhìn toàn diện về sự phát triển của nghiên cứu về logistics được phẩm qua các giai đoạn công nghiệp.

Kết quả nghiên cứu: Dữ liệu chỉ ra sự gia tăng đáng kể về số lượng nghiên cứu trong lĩnh vực logistics được phẩm, đặc biệt từ năm 2016 trở đi, với một sự tăng trưởng mạnh mẽ sau năm 2019, có thể liên quan đến tác động của đại dịch COVID-19. Các công nghệ nổi bật trong nghiên cứu bao gồm blockchain, Internet of Things (IoT), trí tuệ nhân tạo (AI) và tự động hóa, những yếu tố đang cách mạng hóa chuỗi cung ứng được phẩm. Các chủ đề chủ yếu trong nghiên cứu là chuỗi cung ứng được phẩm, blockchain và IoT, phản ánh sự gia tăng của công nghệ trong việc bảo mật và tối ưu hóa phân phối được phẩm. Hơn nữa, AI, tự động hóa và chuyên đổi số được xác định là những xu hướng phát triển mạnh trong logistics được phẩm.

Kết luận: Kết quả nghiên cứu nhấn mạnh ảnh hưởng lớn của công nghệ trong sự phát triển của logistics được phẩm hiện đại. Các công nghệ như blockchain, IoT và AI đang giúp nâng cao tính minh bạch, hiệu quả và khả năng phục hồi của chuỗi cung ứng. Các nghiên cứu trong tương lai cần tập trung vào tối ưu hóa các hệ thống quyết định dựa trên AI, nghiên cứu tính bền vững trong chuỗi cung ứng được phẩm và giải quyết các thách thức về an ninh thuốc và ngăn ngừa hàng giả.

Từ khóa: Phát triển hệ thống Logistics được phẩm; Các cuộc cách mạng công nghiệp; Phân tích thư mục; Blockchain; Internet of Things (IoT); Trí tuệ nhân tạo; Quản lý chuỗi cung ứng; Chuyên đổi số.

1. Literature review

Pharmaceutical logistics ensures the effective distribution of medicinal supplies, waste disposal, sterilization, and related activities. It relies on advanced supply chain strategies and technology, particularly in the private sector, to enhance efficiency and reduce costs [9], [19]. Challenges include managing logistics risks, maintaining supply chain integrity [14], and preventing drug shortages through robust inventory and distribution strategies [10]. Innovative technologies like AI, IoT, blockchain, and Halal logistics principles improve operational efficiency, patient safety, and product quality [3], [15]. Thermolabile pharmaceuticals require specialized protocols to preserve efficacy [2], and adherence to global standards like GDP and GMP is essential for safety [13].

The industrial revolution has driven technological advancements in pharmaceutical logistics, optimizing resource allocation and regulatory compliance [16]. Industry 4.0 technologies, such as blockchain, IoT, and AI, enhance transparency, traceability, and operational efficiency while mitigating fraud [12], [21]. Automated agreements and IoT improve live tracking and liability [12]. Circular economy principles, like RTIs with intelligent technologies, offer sustainable waste mitigation [18]. Despite progress, challenges include building resilient reverse logistics and aligning strategies among stakeholders [18]. Overall, pharmaceutical logistics exemplifies the integration of technology, innovation, and planning to address modern challenges and guide future research [12], [6].

Advancements in technology have significantly improved pharmaceutical logistics, but challenges in scalability and regulatory compliance remain. Addressing these issues requires ongoing research and collaboration. Recent studies highlight the impact of advanced technologies like Big Data Analytics (BDA) and Artificial Intelligence (AI). Bag et al. (2023) detailed how these tools enhance supply chain absorptive capacity across industries [1]. Furstenau et al. (2022) identified key technologies, including ERP, RFID, and blockchain, that transform logistics management [7]. Despite progress in tracking, inventory management, and efficiency, research on the evolution of pharmaceutical logistics through industrial revolutions remains limited.

2. Methodology

To furnish a quantitative evaluation of the scholarly literature about pharmaceutical logistics, a bibliometric analysis was undertaken. This methodological approach was first articulated by Pritchard in 1969 [17]. Research articles disseminated in scholarly journals, monographs, patents, and conference proceedings were systematically gathered and cataloged within bibliographic databases. Information retrieved from these repositories (such as citations, keywords, titles, journals, authors, and institutions) was employed to facilitate scientific evaluation studies through bibliometric methodologies [8]. Utilizing bibliometric techniques can grant essential revelations in a research discipline, marking its confines, pinpointing pivotal authors, and

disclosing future research possibilities [4], [5]. This methodology was selected for the present investigation owing to its proficiency in objectively analyzing the existing framework of the research discipline [22]. The primary aim of this investigation is to assess the existing knowledge framework about the evolution of pharmaceutical logistics systems throughout the various phases of industrial revolutions; consequently, the bibliometric analysis methodology was utilized. Bibliometric analysis serves as a robust instrument for pinpointing the most prominent scholars, funding bodies, institutions, nations, academic collaborations, and pivotal terminology employed in scholarly research [20]. In pursuit of the research aims, metadata from published literature concerning pharmaceutical logistics and the phases of industrial revolutions were extracted from the Scopus database. Specifically, key terms were employed, and a BOOLEAN formula was implemented to formulate the subsequent search expression:

("Pharmaceutical logistics" OR "Pharmaceutical supply chain" OR "Healthcare logistics" OR "Pharmaceutical distribution") AND ("Industrial revolution" OR "Industry 1.0" OR "Mechanization" OR "Steam engine" OR "Industry 2.0" OR "Electrification" OR "Mass production" OR "Industry 3.0" OR "Automation" OR "Computing" OR "Industry 4.0" OR "Digital transformation" OR "Smart manufacturing" OR "Cyber-physical systems" OR "IoT" OR "Industry 5.0" OR "AI-driven manufacturing" OR "Artificial intelligence").

3. Results

Metadata from 113 articles was extracted and analyzed using MS Excel 2016 and Bibliometrix in R.

3.1. Descriptive analysis of the research trends

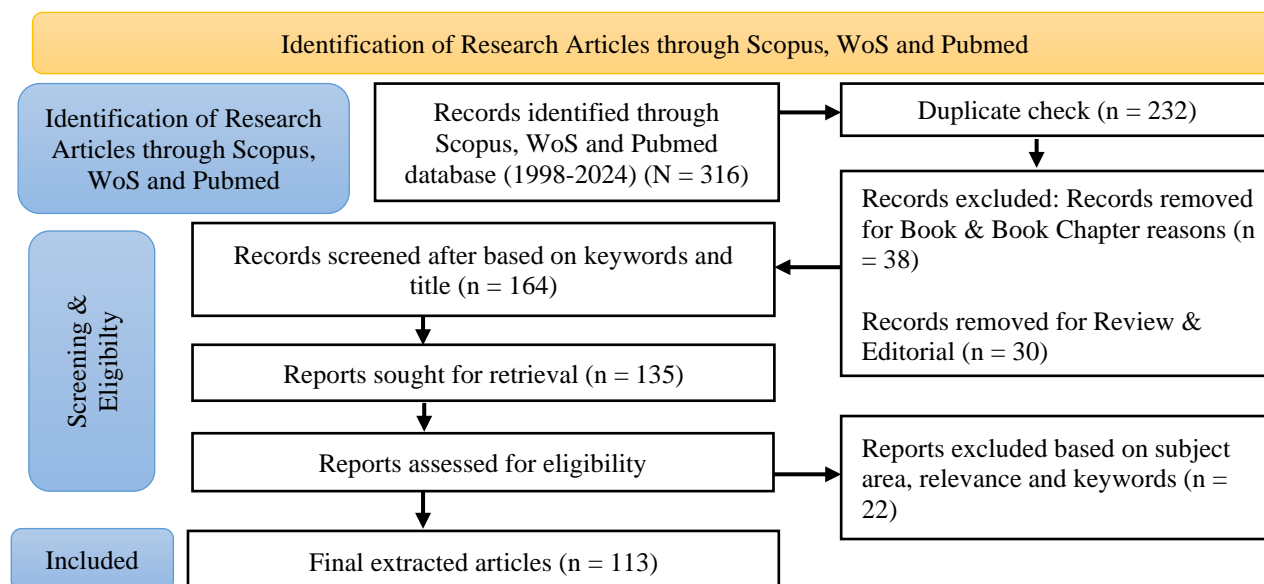


Figure 1. PRISMA-based flowchart for article selection

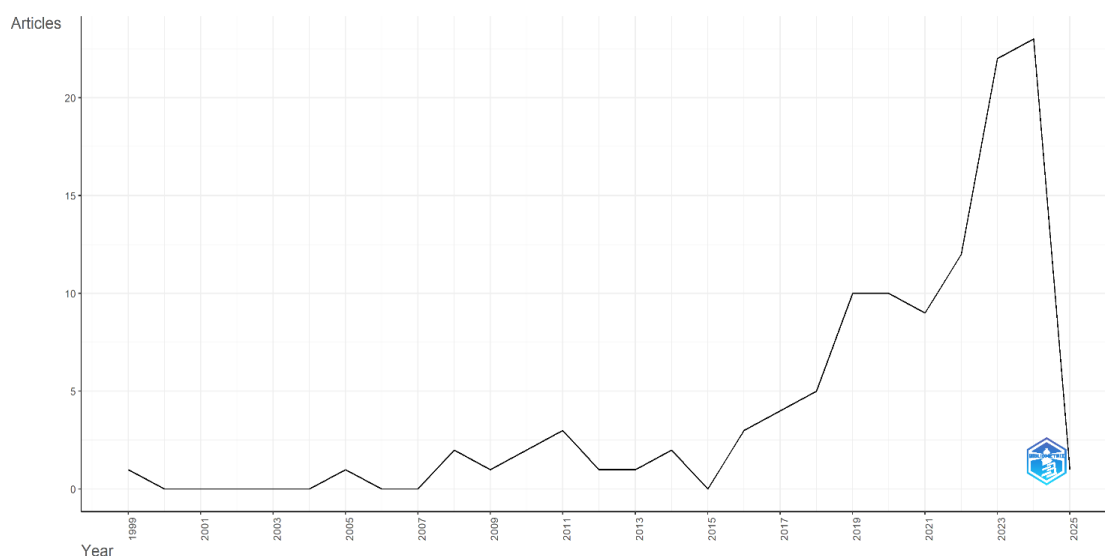


Figure 2. Annual scientific production trend

From Figure 2, in the period 1999-2015, the number of scientific publications remained relatively low, indicating limited research interest in the field. However, from 2016 to 2019, there was a gradual increase in publications, reflecting growing attention to modern technologies such as Industry 4.0, artificial intelligence (AI), blockchain, and the

Internet of Things (IoT) in pharmaceutical supply chain management. Notably, the period 2020-2023 witnessed a sharp rise in research output, peaking in 2023. This surge may be attributed to the impact of the COVID-19 pandemic, which emphasized the importance of pharmaceutical logistics in vaccine distribution, supply chain resilience, and digital

transformation. However, in 2024, the number of publications declined significantly, which could be due to incomplete data for the current year or a shift in research focus toward emerging trends in pharmaceutical supply chain management.

This trend highlights the increasing role of technology and innovation in pharmaceutical logistics while underscoring the need for continued research on the impact of industrial revolutions on modern logistics systems.

3.2. Most relevant sources in pharmaceutical logistics research

Table 1. Most relevant sources based on Bradford’s law

Rank	Sources	Freq	cumFreq	Zone
1	Association for computing machinery (ACM) International conference proceeding series	3	3	Zone 1
2	Computers and industrial engineering	3	6	Zone 1
3	Procedia manufacturing	3	9	Zone 1
4	American journal of health-system pharmacy	2	11	Zone 1
5	International journal of logistics research and applications	2	13	Zone 1
6	International journal of production research	2	15	Zone 1
7	Journal of pharmaceutical policy and practice	2	17	Zone 1
8	1st International conference on the advancements of artificial intelligence in African context AAIAC 2023	1	18	Zone 1
9	2011 2nd International conference on artificial intelligence management science and electronic commerce AIMSEC 2011 - proceedings	1	19	Zone 1
10	2017 13th International wireless communications and mobile computing conference iwcmc 2017	1	20	Zone 1

The analysis of Table 1 reveals the most relevant sources for research on pharmaceutical logistics and industrial revolutions, classified according to Bradford’s Law. The core sources (Zone 1) include journals and conference proceedings that contribute significantly to the field. The top-ranked sources, such as ACM International Conference Proceeding Series, Computers and Industrial Engineering, and Procedia Manufacturing, highlight the technological and industrial dimensions of pharmaceutical logistics, emphasizing the integration of computing, AI, and industrial engineering. Additionally, journals like the International Journal of Logistics Research and Applications and International Journal of Production Research indicate the crucial role of logistics and supply chain management in pharmaceutical distribution. The inclusion of

health policy-related journals, such as the Journal of Pharmaceutical Policy and Practice, suggests that regulatory and governance aspects are integral to this field. Furthermore, the presence of AI-focused conferences, including the 1st International Conference on the Advancements of Artificial Intelligence in African Context (AAIAC 2023), signifies the increasing role of automation, digital transformation, and real-time tracking technologies in pharmaceutical supply chains. These findings highlight the interdisciplinary nature of pharmaceutical logistics research, combining elements of engineering, policy, and healthcare innovation. Future research should explore citation impact and geographic distribution to identify leading contributors and emerging trends in the field.

3.3. Most cited articles in pharmaceutical logistics and industry 4.0

Table 2. Top 10 most cited articles on pharmaceutical logistics and industry 4.0

Rank	Title article	Year	Cited by	Publisher
1	Blockchains everywhere - A use-case of blockchains in the pharma supply chain	2017	481	IEEE
2	Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains	2018	243	Institution of Chemical Engineers
3	Internet of things-based blockchain for temperature monitoring and counterfeit pharmaceutical prevention	2020	139	Sensors
4	Blockchain for the IoT: Privacy-preserving protection of sensor data	2019	123	Association for Information Systems
5	A comprehensive review of blockchain and the Internet of Things in healthcare	2021	73	John Wiley and Sons Inc
6	Drug governance: IoT-Based blockchain implementation in the pharmaceutical supply chain	2020	73	IEEE
7	A non-fungible token solution for the track and trace of pharmaceutical supply chain	2022	53	MDPI
8	Internet of things (IoT)? Blockchain-enabled pharmaceutical supply chain resilience in the post-pandemic era	2023	51	Higher Education Press Limited Company
9	Blockchain in healthcare opportunities, challenges, and possible solutions	2020	49	IGI Global
10	Resilient and sustainable supplier selection: an integration of SCOR 4.0 and machine learning approach	2023	42	Taylor and Francis Ltd.

The analysis of Table 2 highlights the top 10 most cited articles in pharmaceutical logistics, with a strong focus on blockchain, IoT, and Industry 4.0 applications. The most cited work, Bocek et al. (2017; 481 citations), underscores the critical role of blockchain technology in securing and optimizing pharmaceutical supply chains. Similarly, Singh et al. (2020; 139 citations) and Chanson et al. (2019; 123 citations) emphasize IoT and privacy-preserving blockchain solutions, reflecting the increasing reliance on real-time monitoring and counterfeit prevention in logistics. The second most cited article, Ding (2018; 243 citations), provides a comprehensive review of Industry 4.0 and sustainable pharmaceutical supply chains,

highlighting automation and AI integration. Recent studies, such as those by Chen et al. (2023; 51 citations) and Khan et al. (2023; 42 citations), focus on post-pandemic supply chain resilience, emphasizing the need for AI-driven decision-making and supplier selection strategies. The inclusion of Chiacchio et al. (2022; 53 citations), which explores Non-Fungible Tokens (NFTs) for pharmaceutical track-and-trace, suggests emerging interest in digital asset-based traceability solutions. The diversity of publishers (IEEE, Taylor & Francis, MDPI, IGI Global) reflects the interdisciplinary nature of this research, bridging engineering, healthcare, and logistics. These findings demonstrate that future advancements in

pharmaceutical logistics will likely focus on blockchain-enabled transparency, AI-powered

supply chain optimization, and sustainability-driven logistics solutions.

3.4. Keyword co-occurrence and thematic trends

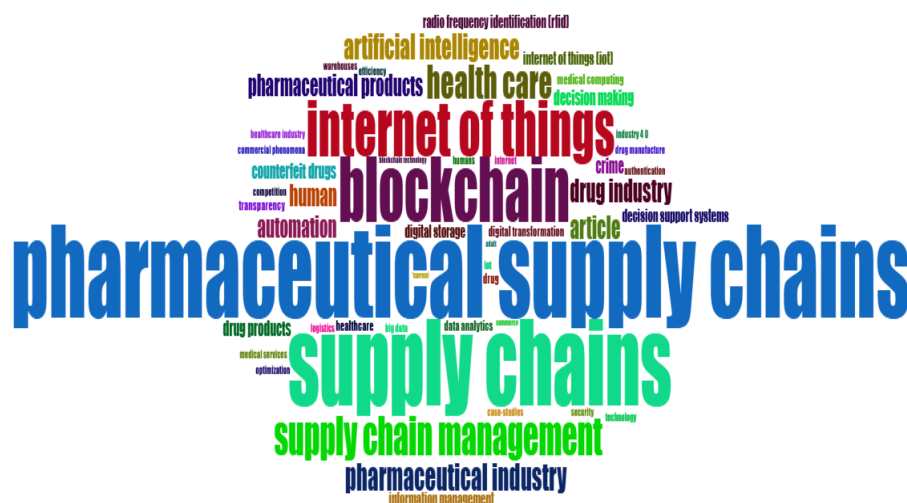


Figure 4. Keyword co-occurrence analysis in pharmaceutical logistics research

The keyword co-occurrence analysis in Figure 4 highlights the primary research themes in pharmaceutical logistics. The most frequently appearing terms, such as “pharmaceutical supply chains,” “supply chains,” and “supply chain management,” confirm that the field focuses on optimizing distribution and logistics within the pharmaceutical industry. A significant emphasis on technological advancements is evident through keywords like “blockchain,” “Internet of Things (IoT),” “artificial intelligence,” and “automation,” indicating a strong trend toward digital transformation and real-time monitoring. Security concerns are also a major focus, as seen in terms like “counterfeit drugs,” “security,” and

“authentication,” reflecting efforts to enhance traceability and prevent fraud in pharmaceutical distribution. The presence of “Industry 4.0,” “decision making,” and “data analytics” suggests an increasing reliance on AI-driven logistics, predictive analytics, and automation for supply chain optimization. These findings illustrate the growing intersection between technology, logistics, and healthcare to improve efficiency, security, and resilience in pharmaceutical supply chains. Future research should further explore emerging digital solutions and their impact on supply chain sustainability and scalability.

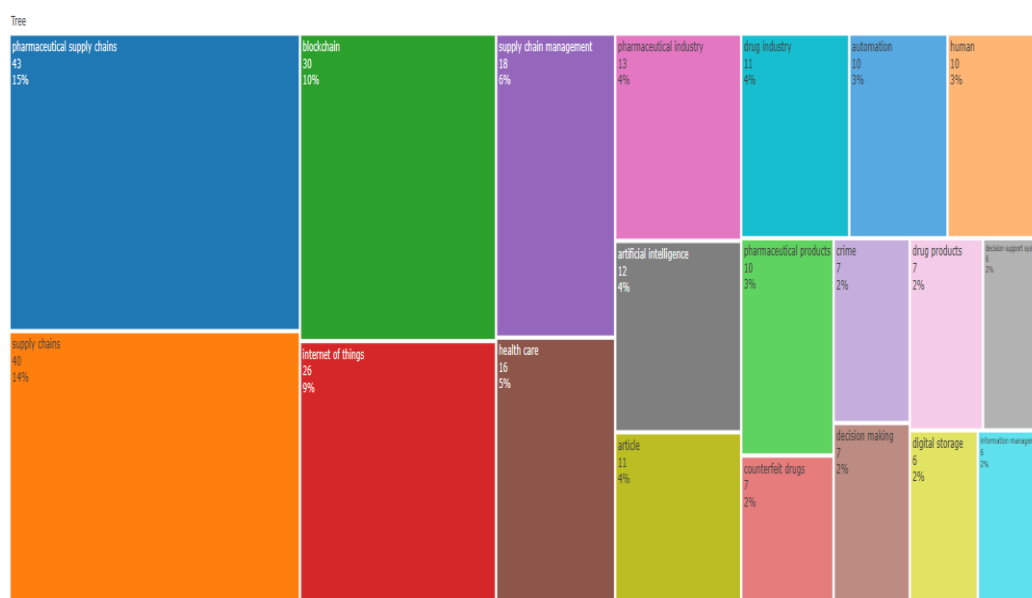


Figure 5. Treemap of key research topics in pharmaceutical logistics

The treemap visualization in Figure 5 categorizes and ranks key research topics in pharmaceutical logistics based on their frequency of occurrence. The most dominant themes, “pharmaceutical supply chains” (13%) and “supply chains” (14%), confirm that logistics efficiency and resilience are central to this research domain. Technological advancements, particularly “blockchain” (10%) and “Internet of Things (IoT)” (9%), highlight the increasing role of digital security, transparency, and real-time monitoring in pharmaceutical logistics. Additionally, “artificial intelligence” (4%) and “automation” (3%) indicate a growing interest in AI-driven decision-making, predictive analytics, and automated logistics operations. The presence of “pharmaceutical industry” (4%) and “health care” (5%) underscores the connection between logistics, healthcare regulations, and patient-centered supply chain management. Furthermore, security concerns are evident through terms like “crime” (3%) and “counterfeit drugs” (2%), emphasizing the need for fraud prevention, authentication, and regulatory compliance. The inclusion of “decision support systems” and “digital storage” reflects a shift toward data-driven logistics solutions. These findings suggest

that future research should focus on enhancing technological integration, security, and decision-making capabilities in pharmaceutical supply chains.

3.5. Keyword density and co-occurrence networks

Figures 6 and 7 provide a comprehensive view of key pharmaceutical logistics research trends, emphasizing thematic focus and interconnections between topics. The keyword density map (Figure 6) highlights areas of high research concentration, while the co-occurrence network (Figure 7) reveals how topics are interrelated, forming structured research clusters. Both figures confirm that “pharmaceutical supply chains,” “blockchain,” and “Internet of Things (IoT)” are the most dominant themes, reflecting the increasing role of digital transformation, real-time tracking, and security in pharmaceutical logistics. The strong presence of “authentication,” “counterfeit drugs,” and “crime” in both figures suggests that supply chain security and regulatory compliance remain critical concerns. Furthermore, artificial intelligence (AI), data analytics, and decision support systems are emerging as essential tools

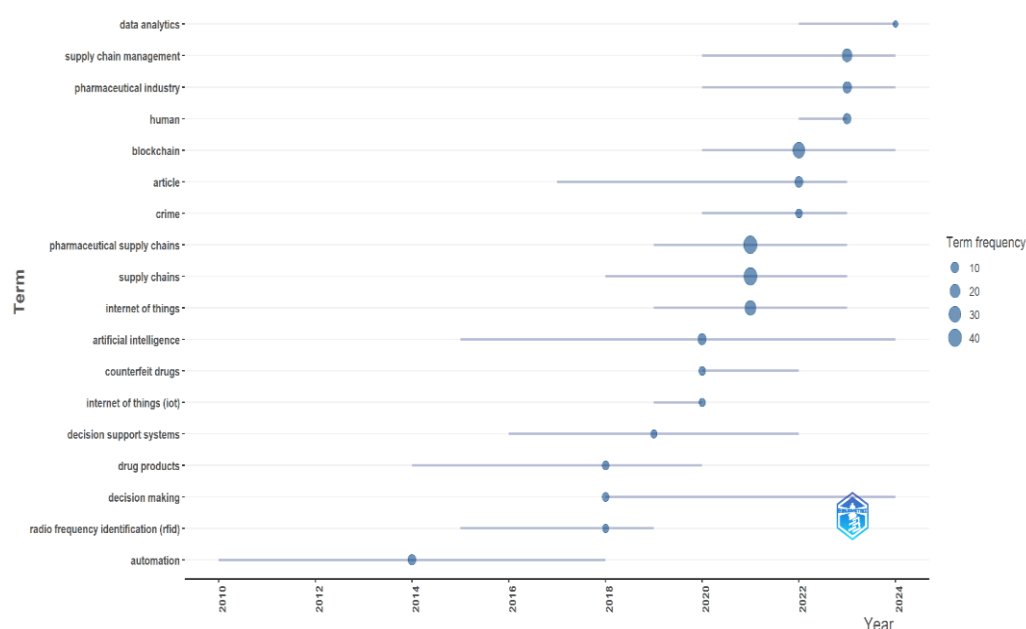


Figure 8. Emerging trend topics in pharmaceutical logistics research

Recent years (2021–2024) have seen a significant increase in research on “pharmaceutical supply chains,” “supply chain management,” and “data analytics,” suggesting a shift toward AI-driven, data-centric logistics optimization. The continued prominence of “crime,” “counterfeit drugs,” and “decision support systems” reflects ongoing concerns regarding regulatory compliance and drug authentication. The integration of Industry 4.0 and 5.0 technologies, particularly blockchain, IoT, and AI, underscores a shift toward predictive analytics, automation, and decentralized supply chain models. These

findings suggest that future research will likely focus on AI-driven resilience strategies, sustainable pharmaceutical logistics, and advanced security frameworks to enhance supply chain integrity.

Figures 9 and 10 provide a comprehensive overview of key research themes in pharmaceutical logistics, highlighting both conceptual structures and thematic trends. The conceptual structure map (Figure 9), generated using Multiple Correspondence Analysis (MCA), illustrates the relationships between major research topics.

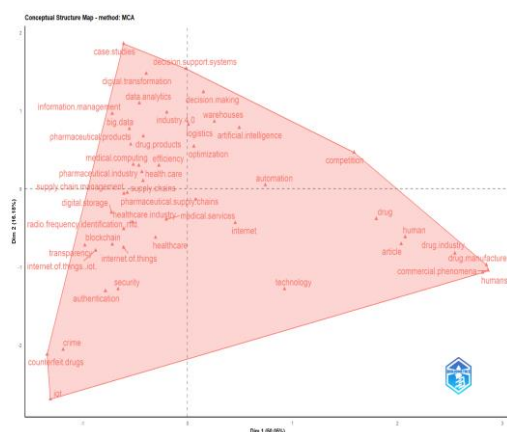


Figure 9. Conceptual structure map of pharmaceutical logistics research (MCA method)

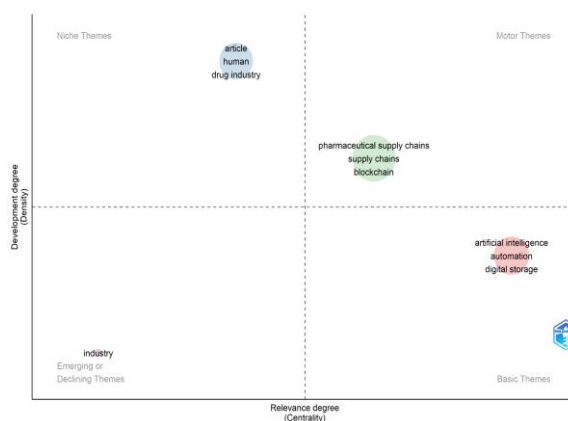


Figure 10. Thematic map of research trends in pharmaceutical logistics analysis & interpretation

At the core of the map, "pharmaceutical supply chains," "blockchain," "Internet of Things (IoT)," and "supply chain management" emerge as the most influential themes, reinforcing their central role in digital transformation and logistics optimization. Additionally, security-related concerns, including "authentication," "transparency," and "counterfeit drugs," are strongly associated with blockchain and IoT, reflecting a focus on fraud prevention and supply chain integrity. Meanwhile, "artificial intelligence," "decision support systems," and "automation" appear in the upper quadrant, indicating the increasing integration of AI-driven decision-making and logistics efficiency solutions. On the right side of the map, "drug industry," "drug manufacture," and "commercial phenomena" suggest research interest in the economic and workforce aspects of supply chain management.

The thematic map (Figure 10) categorizes research topics based on centrality (importance) and density (development level). The motor themes (top-right quadrant), which include "pharmaceutical supply chains," "supply chains," and "blockchain," are the most developed and highly relevant areas of research, confirming their dominance in pharmaceutical logistics. In contrast, basic themes (bottom-right quadrant), such as "artificial intelligence," "automation," and "digital storage," indicate emerging but underdeveloped research directions, suggesting a growing focus on AI-driven logistics solutions and automated supply chain management. Niche themes (top-left quadrant), including "human," "drug industry," and "article," represent specialized but less central topics, while "industry" (bottom-left quadrant) is classified as either a declining or emerging theme, suggesting the need for further exploration of broader industrial applications in pharmaceutical logistics.

These findings emphasize that blockchain, IoT, and digital security solutions are already well-integrated into pharmaceutical supply chain research, while AI, automation, and predictive analytics remain underexplored but rapidly expanding areas. Future research should focus on enhancing AI-driven decision-making, optimizing automation in logistics, and investigating the economic and human impacts of digital transformation in the pharmaceutical supply chain.

4. Conclusion

This bibliometric review examined the evolution of pharmaceutical logistics through the different stages of industrial revolutions. The findings underscore the significant impact of technological advancements, such as blockchain, Internet of Things (IoT), and artificial intelligence (AI), on the development of pharmaceutical logistics. Over time, these technologies have gradually transformed the pharmaceutical supply chain, enhancing transparency, efficiency, and security. The research trend, as indicated by the bibliometric analysis, has shown a marked increase since 2016, with a particularly sharp rise post-2019, likely attributed to the COVID-19 pandemic's impact on supply chain resilience and vaccine distribution.

The study highlights that pharmaceutical logistics has become increasingly reliant on digital transformation and automation, with technologies like AI driving decision-making and blockchain enhancing traceability and security. Furthermore, the shift toward Industry 4.0 and 5.0 technologies has fostered a more integrated, data-driven approach to logistics operations, making the supply chain more resilient and adaptable to unforeseen challenges.

Given these insights, future research in this field should focus on further exploring the integration of AI-driven logistics optimization,

the role of blockchain in ensuring security, and the potential for sustainability in pharmaceutical supply chains. Additionally, further studies should examine the broader implications of Industry 4.0 and 5.0 on global pharmaceutical logistics, including supply chain ethics, regulatory challenges, and the human workforce's adaptation to these changes.

While this bibliometric review offers valuable insights into the development of pharmaceutical logistics across industrial revolutions, there are several limitations to consider. First, the scope of this study was confined to academic publications indexed in Scopus, Web of Science, and PubMed, which may not capture all relevant research, particularly those from emerging sources or local/regional journals. As a result, some important perspectives or innovations may have been overlooked.

Second, the study primarily relied on the available bibliometric data, which may not fully reflect the nuances of the underlying research, such as the specific contributions of individual authors or the real-world applications of the technologies discussed. The reliance on citation counts may also bias the review toward more established or widely recognized studies, potentially overlooking innovative or cutting-edge research that has not yet gained significant citation attention.

Lastly, the rapidly evolving nature of the pharmaceutical logistics field, particularly in the context of the COVID-19 pandemic and subsequent technological advancements, means that some of the data and trends analyzed in this review may be subject to change. Future research should continue to monitor and update bibliometric analyses to reflect the latest developments in the field, especially as emerging technologies like AI, blockchain, and IoT continue to shape the future of pharmaceutical supply chains.

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