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Digital transformation of the Pharmaceutical Industry: A future research agenda for management studies

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ABSTRACT

Despite the widespread attention given to Digital Transformation (DT), there is a notable lack of comprehensive knowledge concerning its implications within the Pharmaceutical Industry (PI), particularly from a Management Studies perspective. This research employs a Systematic Literature Review approach, utilizing an initial review of 404 articles (which resulted in the identification of 35 relevant papers) to propose a comprehensive Future Research Agenda focusing on key technologies driving PI-DT and addressing the major gaps in current literature. Specifically, four primary research directions are delineated in the areas of (I) Operations Management, (II) Strategic Management, (III) Organization's Theory, and (IV) Stakeholder's Theory. In conclusion, the Literature Review addresses the underdeveloped field of PI-DT in Management Studies, offering the theoretical foundation for further scholarly inquiry and knowledge development in this field.

1. Introduction

Over the past decade, digital transformation (DT) has emerged as a pivotal force, redefining the operational, strategic, and competitive landscapes across various industries (e.g., Song et al., 2024; Appio et al., 2021; Gastaldi et al., 2018; Llopis-Albert et al., 2021; Leão and da Silva, 2021 to mention a few). This phenomenon, driven by the rapid convergence (Appio et al., 2023) of the internet, emerging technologies, and automation, has acquired extensive attention from scholars and practitioners alike (Hausberg et al., 2019; Vial, 2019). Yet, in the Pharmaceutical Industry (PI), a sector where innovation is both a constant demand and a critical challenge (Achilladelis and Antonakis, 2001; Malerba and Orsenigo, 2015), DT's journey is still unfolding. The exploration of DT within PI, particularly through a management studies lens, is sparse, indicating a significant gap between the potential of DT and its current scholarly examination.

The PI stands at a crucial juncture, with DT offering unprecedented opportunities to enhance drug Value Chain Phases (VCP) — from Drug Discovery (DD) and Clinical Trials (CT) to Manufacturing (MK), Supply Chain (SC), and Market Access (MA). Technologies such as the Internet of Things (IoT), Augmented Reality (AR), Artificial Intelligence (AI), Blockchain, Cybersecurity, Cloud Computing, 3D Printing, Digital Twins, Virtual Reality (VR), Robotics, and Big Data are poised to drive transformative changes (e.g., Silva et al., 2020; Kulkov, 2021; Sharma et al., 2022; Reinhardt et al., 2020). However, the academic dialogue around these technological integrations in PI, especially from a management perspective, remains in its nascent stages. The discourse is often limited to practice-oriented phenomena, with substantial insights buried in practitioner's journals or generalized within the broader healthcare context, thus overlooking the nuanced implications for management studies (e.g., Hariry et al., 2022; Kraus et al., 2021). Acknowledging the profound need to supplement the theoretical aspects of DT in PI and to unravel the complex interplay between emerging technologies and management practices, a systematic literature review (SLR) was performed following the methodology outlined by Tranfield et al. (2003). This rigorous review of 404 articles, employing stringent selection criteria, distilled down to 35 papers that resonate with the research objectives of this study.

The analytical journey through these selected works uncovered four pivotal research domains: Operations Management Research, Strategic Management Research, Organization's Theory Research, and Stakeholder's Theory Research. Each domain offers a unique vantage point to dissect and understand the multifaceted impacts of DT within PI, underscoring the urgency for a robust theoretical framework that can

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guide both scholarly inquiry and practical applications.

This paper endeavors to synthesize the fragmented landscape of DT research in PI, offering a coherent picture of its current state and carving out a structured research agenda that lays the groundwork for future inquiries. The objective of this study is twofold: first, to synthesize the extant research into a cohesive overview that elucidates the current contours of DT within PI, particularly emphasizing management implications, and highlighting the critical role of management studies in deciphering the multifaceted impacts of DT on PI; second, to identify and articulate the critical research gaps and potential directions, thus catalyzing a robust academic inquiry into DT's role in reimagining the pharmaceutical landscape, advocating for a theoretical enrichment that matches the practical advancements in the field.

Overall, this paper is not just a call to arms for bridging the theoretical voids in PI-DT; it is an invitation to the academic community to engage with, debate, and advance the discourse on digital transformation in the pharmaceutical industry. Through a structured presentation of the research gap and a clear articulation of the research aims, this study aims to enrich the ongoing conversation around DT, offering a scaffold for both theoretical advancement and empirical exploration, ensuring that the transformative potential of DT is fully realized in advancing healthcare outcomes.

The paper first unveils the research gaps identified, employing a structured approach for clarity. Following this, it describes the investigation methodology, navigating through the selected articles to distill key themes and insights. A detailed discussion on the future research agenda, derived from the analysis, aims to spark scholarly dialogue and exploration. Lastly, a reflection on the theoretical and practical implications of the findings is offered, setting the stage for a concluding synthesis that highlights the main research limitations and articulates the core takeaways.

2. Research gap

This study is situated in the Pharmaceutical Industry (PI). The PI comprises multiple companies that collaborate and compete to research, develop, manufacture, and distribute drugs for diagnosing, curing, mitigating, treating, and preventing diseases (Tinkle et al., 2014). This industry involves a complex set of stakeholders interacting in various Value Chain Phases (VCP), including *Drug Discovery* (DD), *Clinical Trials* (CT), *Manufacturing* (MK), *Supply Chain* (SC), and *Market Access* (MA). Before the Covid Pandemic, there was worrying evidence of PI's poor digital deployment. According to a Deloitte survey,[1] most of the companies were either in the early Phases of Digital adoption (25 %) or developing their capabilities (55 %); and only 20 % reported themselves to be digitally mature. Nevertheless, the Covid Pandemic consistently empowered PI-DT, such that a pandemic era survey[2] showed that companies had become keener to invest in and take risks with DT across different VCP. This promising trend is also reflected by the growing attention PI-DT has gained in practitioners' literature. However, despite the volume of works discussing PI-DT, only a few have been conducted under a Management lens (Nambisan et al., 2019; Nambisan et al., 2017; Vial, 2019; Lee and Lee, 2021; Walsh et al., 2020). This demonstrates a substantial limitation in the literature; thus, more comprehensive studies are required to expand academic debates in DT. The first significant problem addressed by this study is that most of the current literature on PI-DT has been debated under a Scientific Perspective or through a practical lens of application without projecting the phenomenon as a long-term inquiry to be investigated under a Management perspective. For instance, Polykovskiy et al. (2018) studied AI applications to address rare diseases; Lusci et al. (2013) adopted deep learning architectures to predict aqueous solubility for drug-like molecules; Moreno-Benito et al. (2022) examined Digital Twins in the context of continuous manufacturing and the digital design of drugs, while Algahtani and Ahmand (2022) discussed 3D printing adoption to develop a self-nano-emulsifying drug delivery system.

Despite the great relevancy of these topics within the management debate, the above works are more concerned with advancing the scientific or practical knowledge within the field rather than opening new research questions to future researchers. This creates an interesting opportunity to establish consistent foundations in the Management PI-DT Literature, and this paper will address this latent problem.

Another reason is that the most relevant PI-DT works are situated within the broader Healthcare setting (Dal Mas et al., 2023; Kraus et al., 2021). Although PI falls under the *Healthcare* umbrella, these articles include other sector's implications, such as those of the *Hospital Industry* or *Pharmacies*. For instance, J. Liu et al. (2021b) discussed the implementation of a Cloud-Based pre-prescription system for pharmacies and clinicians to minimize the prescription of inappropriate medications; Kohl et al. (2019) investigated the use of Big Data techniques in Hospitals; while Ho et al. (2023) conducted research on the acceptance of emotional AI for aiding the elderly or individuals with physical disabilities. Thus, to fill the gap in the PI-DT Management studies area, this more comprehensive and focused research has been engaged.

Although some research has been conducted within the PI-DT Management field, it has been limited to addressing only a single drug's VCP or individual Technologies. Although these works support the creation of PI-DT as a stream of research in Management Studies, they are restrictive as they only represent distinct or narrow issues within DT. For instance, the article from Zulfiqar et al. (2022) discusses adoption of Blockchain technology to fight counterfeited drugs; Coito et al. (2022) evaluates the impact of digital twin for quality control in drug laboratories; and Solfa (2022) examines the impact of cybersecurity and Supply Chain risk management on digital operations. As a result, the subsequently proposed research agendas are often bounded by the prior research constraints. Thus, this study intends to provide a solid, comprehensive foundation within literature by engaging in a broad examination of PI-DT.

There have, however, been some attempts at addressing the broader PI-DT phenomenon. In 2020, Reinhardt et al. surveyed the current DT developments of the Irish Pharma Sector to provide a base of information for developing strategies and future directions. The same year, Silva et al. conducted fieldwork in Portuguese BioPharma Manufacturing based on ten interviews to represent the applications and impacts of Industry 4.0 technologies. These articles have four main common limitations: (1) they describe only general benefits and barriers to PI-DT without discussing in detail different technology patterns across the different drug's VCP; (2) these articles base their contribution primarily on their sample responses, which are often too small to provide diversified perspectives on technology and VCP, without mentioning relevant Literature as theoretical background; (3) these works were conducted before Covid; therefore, they did not consider the recent disruptive developments brought by the pandemic to PI; (4) these articles do not represent future research agendas to be pursued in the Literature of Management PI-DT. This paper aims to address these limitations and provide a more comprehensive understanding of PI-DT through this study.

3. Review methodology

In support of this research, the *Systematic Literature Review* (SLR) methodology (Tranfield et al., 2003) has been used. SLR is a rational, transparent, and replicable research methodology for analyzing the body of knowledge about a specific construct or technology (Sivarajah et al., 2017) exploring, and dedicating available evidence related to a specific research question to replicate it (Kitchenham and Charters,

[1] https://www2.deloitte.com/content/dam/insights/us/articles/4797_CHS-MIT-survey/DI_CHS-MIT-survey.pdf.

[2] https://www2.deloitte.com/content/dam/Deloitte/it/Documents/life-sciences-health-care/DI_Life_sciences_digital_innovation.pdf.

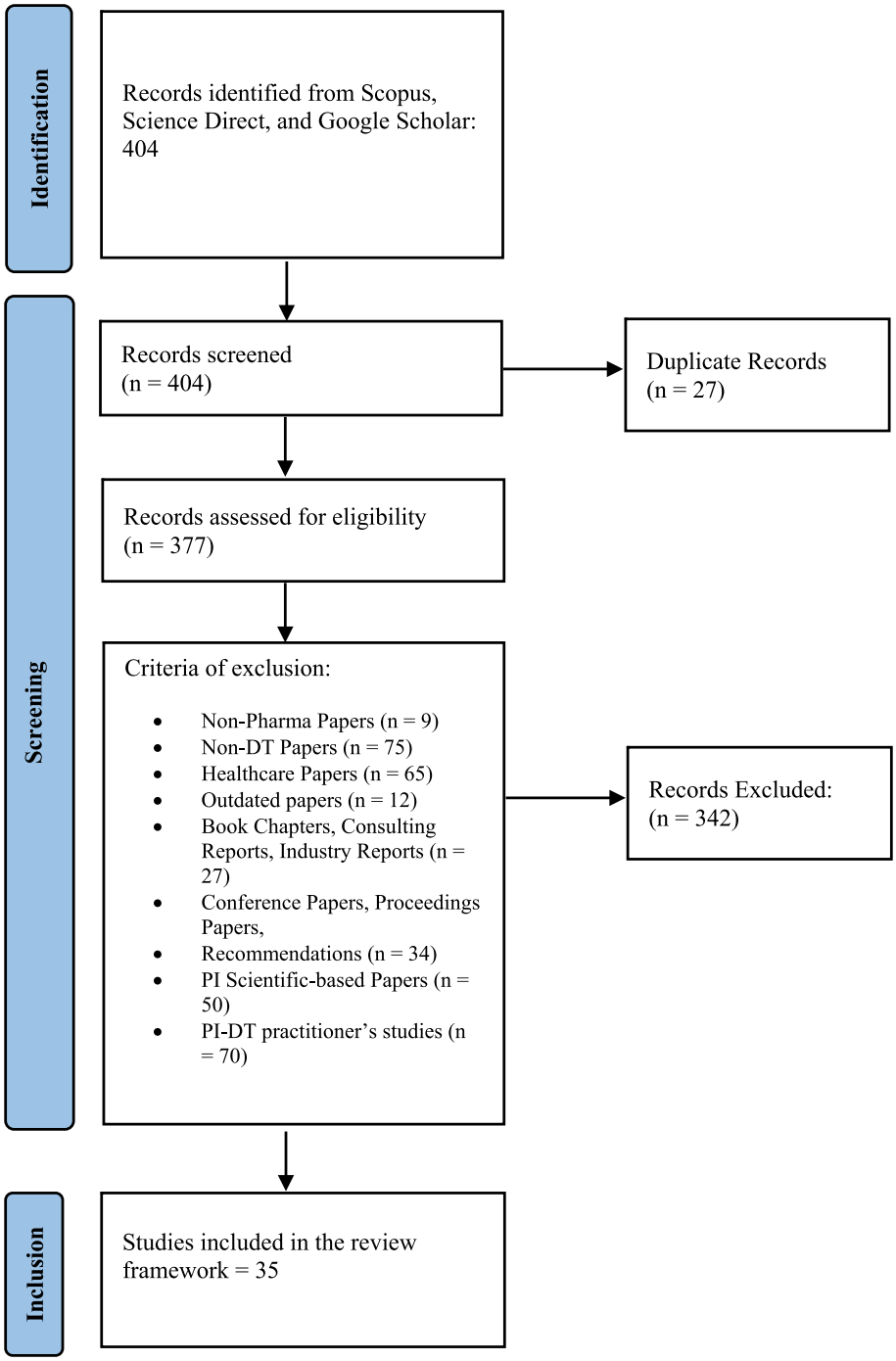

Fig. 1. Review methodology (adopted from PRISMA[1]).
[1]http://prisma-statement.org/prismastatement/flowdiagram.

2007; Nassif et al., 2019; Xiao and Watson, 2019). There are various motivations for conducting an SLR, such as proposing the current state of the art about a specific construct or providing a reference structure identifying current research gaps and potential future study themes (Sivarajah et al., 2017). The review framework carried out in this study follows a *Three-Phase* approach (Tranfield et al., 2003) as illustrated in the following outline:

- *Phase I - Planning the review*, (*a*) *describe the research question, research aims, and* (*b*) *develop a review protocol* (Subsection 3.1);
- *Phase II - Conducting the review, describe the material selection criteria for the research purposes, and divide them into three stages* (Subsection 3.2);
- *Phase III - Reporting and dissemination*, (*a*) *conduct a descriptive analysis of the review framework*, (*b*) *research contributions*, (*c*) *research limitations, and* (*d*) *conclusions* (Section 4).

The articles selected for this comprehensive examination were collected and extracted in *Rayyan Software*[3] to enforce the exclusion

[3] https://rayyan.ai/.

criteria and quality control over the review framework. Afterward, the review framework was examined several times to establish clusters; accordingly, recurrent patterns emerged. By strictly controlling the review process, this method resulted in the analysis of 35 articles, uncovering relations not previously identified in the Management Literature (Sivarajah et al., 2017; David and Han, 2004; Tranfield et al., 2003; Delbufalo, 2012; Singh et al., 2020; Compagnucci and Spigarelli, 2020; Mahmud et al., 2022), Fig. 1 summarizes the review methodology.

3.1. Phase I – planning the review

(a) *Description of Research Question and Research Aims*

Using the guiding principles from Tranfield et al. (2003) and Kitchenham and Charters' (2007) publications, the following research questions, objectives, and protocols to disclose data selection and criteria analysis were developed. To begin, the study originates from the claim made by many practitioners that DT helps renovate business models, establish more agile organizational structures, improve patient care levels, adapt more effectively to competitor's moves or regulatory guidelines, and improve other aspects of a drug's Value Chain Phases (VCP). However, these assertations have been completely disregarded in the Management Literature discussion, lacking a solid research agenda projecting the Pharmaceutical Industry Digital Transformation (PI-DT) phenomenon as a field of study. Accordingly, this research aims to enrich the body of knowledge, focusing on the following research question:

RQ: *What is the future Research Agenda in the PI-DT Management Literature*?

(b) *Development of a Review Protocol*

Below, the design of the relevant material collection of the SLR is described. In particular, the following primary requirements were applied:

- *Requirement I* – The review was conducted from September 2022 until February 2024 by searching the Scopus, Science Direct, and Google Scholar databases. These databases were selected because they are the most well-recognized academic search engines. Accordingly, they include most international peer-reviewed journals worldwide and are likely to offer significant contributions to the area of interest.
- *Requirement II* – To collect only relevant perspectives, all the chosen articles included pertinent keywords and were reviewed with particular attention given to those section(s) that referred explicitly to research objectives.
- *Requirement III* – Only peer-reviewed articles written in English published after 2010 were considered within the review framework. Year 2010 as selected as a cut-off as works preceding this were not likely to yield relevant DT perspectives.
- *Requirement IV* – Because of the varying nature of the research question, various kinds of studies were included, such as qualitative, quantitative, surveys, mixed methods, or literature reviews. Based on the research scope, only those papers that deal with PI-DT under a *Management Studies* perspective were selected.
- *Requirement V* – The final quality control assurance method involved a full-text reading analysis to support researchers in providing relevant contributions.

These requirements were observed rigidly to guarantee an effective and reproducible database searching process (Sivarajah et al., 2017; David and Han, 2004; Tranfield et al., 2003; Delbufalo, 2012; Singh et al., 2020; Compagnucci and Spigarelli, 2020; Mahmud et al., 2022) which will be discussed in the following sub-section.

Table 1
Overview of the selected journals, number of papers, and related research topics.

Journal	Papers	Research topics
Technological Forecasting and Social Change	6	Applied Psychology; Business and International Management; Management of Technology and Innovation
IEEE Transactions on Engineering Management	3	Electrical and Electronic Engineering; Strategy and Management
Journal of Business Research	2	Marketing
International Journal of Production Research	2	Industrial and Manufacturing Engineering; Management Science and Operations Research; Strategy and Management
Annals of Operations Research	1	Decision Sciences (miscellaneous), Management Science and Operations Research
Journal of Industrial Information Integration	1	Industrial and Manufacturing Engineering; Information Systems and Management
Journal of Manufacturing Systems	1	Control and Systems Engineering; Hardware and Architecture; Industrial and Manufacturing Engineering; Software
Journal of Cleaner Production	1	Environmental Science; Industrial and Manufacturing Engineering; Renewable Energy, Sustainability and the Environment; Strategy and Management
Technology in Society	1	Business and International Management; Education; Human Factors and Ergonomics; Sociology and Political Science
Process Safety and Environmental Protection	1	Chemical Engineering; Environmental Chemistry; Environmental Engineering; Safety, Risk, Reliability and Quality
Journal of Open Innovation: Technology, Market, and Complexity	1	Development; Economics, Econometrics and Finance; Sociology and Political Science
Business Process Management Journal	1	Business and International Management, Business and International Management
Heliyon	1	Multidisciplinary
Current Research in Environmental Sustainability	1	Environmental Science
PeerJ Computer Science	1	Computer Science
SN Computer Science	1	Computational Theory and Mathematics; Computer Graphics and Computer-Aided Design; Computer Networks and Communications; Computer Science Applications; Computer Science; Artificial Intelligence
Processes	1	Chemical Engineering; Process Chemistry and Technology; Bioengineering
Futures	1	Business and International Management; Development; Sociology and Political Science
Journal of Industrial Engineering and Management (JIEM)	1	Industrial and Manufacturing Engineering; Strategy and Management
Asian Journal of Business Research	1	Political Science and International Relations; Sociology and Political Science; Business and International Management; Marketing; Strategy and Management
Journal of Commercial Biotechnology	1	Biotechnology; Economics and Econometrics; Management of Technology and Innovation
International Journal of Technology, Innovation and Management (IJTIM)	1	Management of Technology and Innovation
JISR management and social sciences & economics	1	Management Science, Social Sciences and Economics

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Table 1 (*continued*)

Journal	Papers	Research topics
Journal of Supply Chain and Customer Relationship Management	1	Business, Management and Accounting
Management and Economics Review	1	Business, Management and Accounting
Transportes	1	Business, Management and Accounting

3.2. Phase II—conducting the review

The database searching process was conducted in three stages. The following discussion details how these stages were structured.

Stage I - Identification

In the first stage, following Requirement I, the following relevant keywords were used for the database search:

"*#Technology AND Pharma OR Pharmaceutical Industry AND Digital Transformation OR Industry 4.0 AND Literature Review OR #ValueChainPhase*"

As a result, 404 publications were identified.

Stage II – Screening and Exclusion Criteria

In this second stage, an exploratory title, abstract, and keyword analysis have been conducted to exclude certain studies from the research domain. As a first step, duplicate papers ($n = 27$) were eliminated. By keeping in mind that the research objective was to provide PI-DT Management Studies with a cognitive roadmap for future research, non-PI papers ($n = 9$), PI papers not dealing with DT ($n = 75$), and Healthcare Papers ($n = 65$) that failed to mention any PI implications (Requirement II) were excluded. Moreover, Outdated Papers ($n = 12$) and un-peer-reviewed articles such as Book Chapters, Consulting Reports, and Industry Reports (n = 27), and not yet published materials such as Conference Papers, Proceedings Papers, and Recommendations ($n = 34$) (Requirement III) were also excluded. Among the selected peer-reviewed articles, Science-related papers dealing with DT ($n = 50$) and PI-DT practitioner's articles ($n = 70$) were omitted because Science-related papers are too specialized, focusing on topics such as Biology or Chemistry, and practitioner's studies lack Management foundational input, which is required to build a future Research Agenda (Requirement IV).

Stage III – Inclusion

As a result, the study focused on articles including discussions on PI-DT ranging from subject journal from Business and Management Sciences, Computer Sciences, Industrial Engineering Sciences, Sustainability and Environmental Sciences, and Social Sciences. At the end of the screening and exclusion stage, 35 relevant articles were included in the analysis and were then read and analyzed by the authors of this study (Requirement V).

3.3. Phase III - reporting and dissemination of results

The primary purpose of this study is to create a future research agenda for management scholars. The motivation for conducting this investigation comes from the limited amount of research on this topic. To gain insight into the Literature, articles related to PI-DT were thoroughly reviewed, starting with a preliminary group of 404 papers and narrowing it down to a final review framework comprised of 35 relevant articles within the management Literature. Table 1 provides an overview of the review framework belonging journals, while Fig. 2 provides a descriptive statistics considering Years of Publication, Methodology, Technology, and Value Chain Phases (VCP).

There has been a significant rise in the number of articles delving into Pharmaceutical Industry Digital Transformation (PI-DT) since 2018. No relevant works before 2018 were found, confirming the topic's novelty in the Management Literature context. Indeed, PI-DT has consistently gained attention over the years, particularly after the Covid Pandemic, with a notable increase in publications during 2020 and 2022, where more than half of the review framework was published. These findings indicate that the subject is becoming increasingly attractive for scholars, and this research will support future research. According to Fig. 2, researchers are employing a wide range of

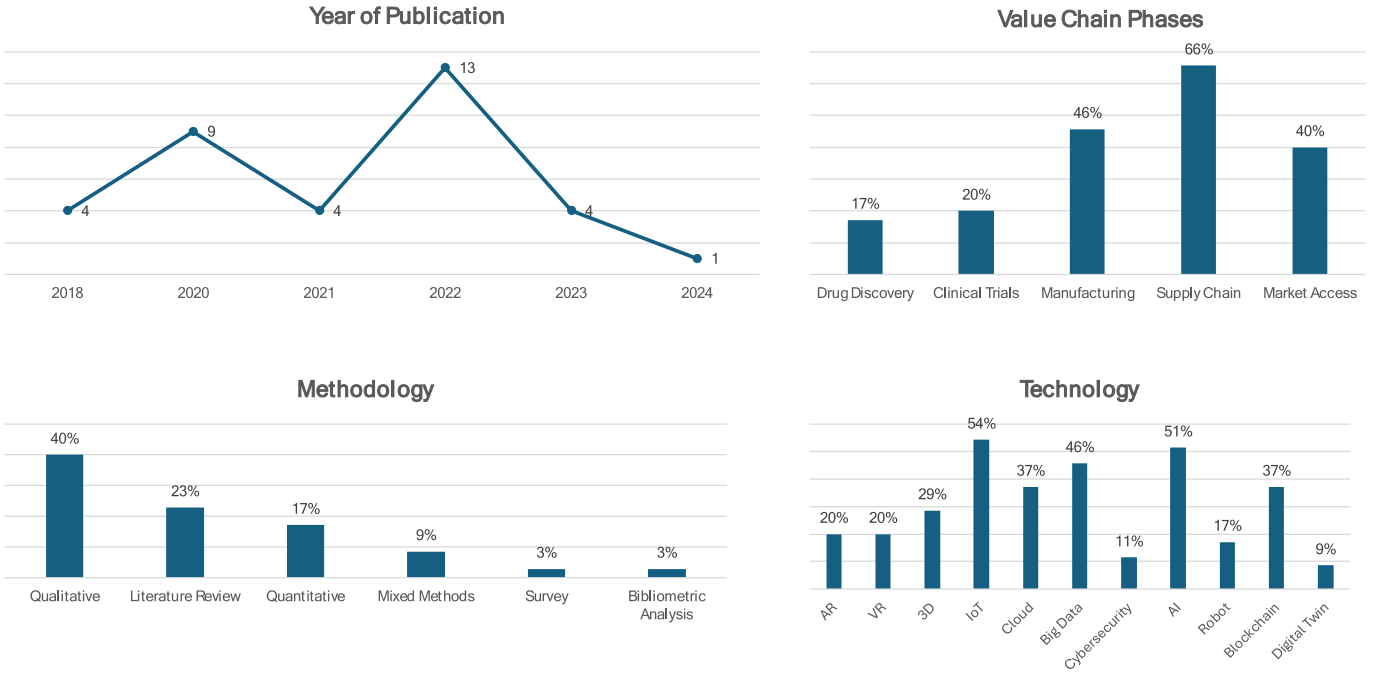

Fig. 2. Descriptive statistics (Abbreviations: Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), Internet of Things (IoT)).

Table 2
Overview of the review framework.

Paper	Research objectives and findings	Topics	Methodology	Value chain phase	Technology included in the study	Limitations and future research for PI-DT management
Silva et al., 2020	To represent current PI-DT Trends, Barriers, and Challenges.	Predictive Maintenance; Quality control and product design; HR Management; Patient Engagement and Monitoring.	Qualitative, Semi structured Interviews with Field Experts	MK, SC, MA	AR, VR, 3D, IoT, Cloud, Big Data, AI	• More research to address Human Performance with Robots in MK; • Understanding Data Integration for the SC through the adoption of DT technologies; • More research deepening the organizational culture shift is needed to address DT Technologies.
Shahzeb Zulfiqar et al., 2022	The paper discusses the potential of Blockchain technology to address current challenges for PI-SC management in Pakistan. It sheds light on various aspects such as the counterfeit medicine market, existing systems, lack of Blockchain expertise, and the need to clarify the role of Blockchain.	Cultural Change; Technology Acceptance; Training; Managerial Awareness and Leadership; Traceability; Product Quality Control; Logistics; Procurement; Track of Products; Need for standardized data sharing protocols; Waste Management	Qualitative, Semi structured Interviews with Field Experts	SC	Blockchain, IoT	• More field research linking procurement of raw materials, Counterfeited drugs, and SC Trust • More research for improving the regulatory framework on tracking counterfeited drugs; • Conduct similar study in other countries in order to uncover cultural biases.
Alharthi et al., 2020	The objectives of this research were: (1) to explore Blockchain opportunities and address related problems in the PI-SC; (2) To identify barriers and challenges related to the adoption and implementation of Blockchain; (3) To develop guidelines for successful implementation of Blockchain technology in the context of Saudi Arabia; (4) To investigate professionals' perceptions regarding the impact of Blockchain adoption in the PI-SC.	Maintenance and Monitoring; Productive Process Reengineering; Scalability; Decision Making and Support; HR Management; Organizational Communication and Learning; Regulatory Compliance.	Qualitative, Semi structured Interviews with Field Experts	SC	Blockchain, Cloud	• Extend this research framework to non-developing countries; • To operationalize and validate the developed theoretical framework through quantitative analysis.
Satwekar et al., 2022	To design a Framework for Digital Innovation Management Orchestration.	Process and Organizational Change; Agile and Flexible Decision-making; Business Model transformation; Technology Lifecycle monitoring.	Qualitative, Action Design Research	MK	AI	• Application of the developed Framework with other technologies in the context of healthcare organizations.
Coito et al., 2022	To establish a method to evaluate the introduction of automation QC laboratories, through a simulation model.	Resource management; Manual Work Reduction; Equipment Maintenance; Job Allocation; Resource efficiency.	Quantitative	MK	Digital Twins	• Adopt the established methodology with more advanced heuristics and dynamic scheduling.
Festa et al., 2018	Creation of a theoretical Framework that addresses the impact of Big Data on Process efficiency and Efficacy.	Business Process Management; Data Standardization; Information Systems Management.	Qualitative, Multiple Case study	DD, CT, MK, SC, MA	Big Data, IoT	• Quantitative Analysis testing the influence among knowledge process standardization (dependent variable) and big data (independent variable) in ambidextrous organizations; • Demonstrating the effectiveness of the developed theoretical Framework through empirical analysis or multiple case studies.
Ghadge et al., 2022	This research aims to link Blockchain to PI-SC building a conceptual framework for implementation and a future research agenda.	Maintenance and Monitoring; Productive Process Reengineering; SC Management; Business Model Innovation; Data Governance and Analytics; Scalability; Decision Making and Support; HR Management; Organizational	Literature Review	CT, SC	Blockchain, IoT, Big Data, Cybersecurity	• To address how Blockchain can enhance sustainability and Circular economy in PI-SC; • To understand how Blockchain can improve Drug Recall Management; • To address how to align and standardize Blockchain practices for data collection on a large scale;

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Table 2 (*continued*)

Paper	Research objectives and findings	Topics	Methodology	Value chain phase	Technology included in the study	Limitations and future research for PI-DT management
		Communication and Learning; Environmental; Impact on Patient; Regulatory Compliance; Social/ Governance.				• More research addressing the transition process from pilot projects to permanent systems; • More studies addressing the scalability for a solid transaction mechanism across different organizations through smart contracts; • Improving the interoperability and compatibility of Blockchain within a wider Industry 4.0 digital technology's ecosystem; • Building performance measurement for Blockchain.
Zakari et al., 2022	Represent the use of Blockchain in PI	Quality control and product design; SC Transparency and Trust; Logistics; Cold Chain; Data Governance; Technology Acceptance; Workforce Turnover; Regulatory Protocols.	Literature Review	SC, MA	Blockchain	• To address how enhanced Data governance through Cloud Computing can prevent counterfeit drugs circulation; • Investigating the interaction between 5G and Blockchain to enhance Cold Chain Control • Barriers to Blockchain adoption: Trust, transparency, Scalability, Integration and Cost; • Development of universal guidelines and rules to drive Blockchain adoption.
Hosseini Bamakan et al., 2021	To represent through Case Studies Blockchain applications in PI.	Data Serialization and Traceability; Data Integrity, Security, Privacy and Transparency; and Waste Management.	Qualitative, Multiple Case study	SC, MA	Blockchain, IoT	• To study Cold Chain Management addressing the Creation, Deployment, Execution and Completion of Smart contracts: • How different Blockchain-based PI Cold Chains can cooperate and interact with each other.
Al-Shura et al., 2018	Through Technology–Organization–Environment (TOE) framework, this article investigates the influence of cloud computing adoption in Jordan PI MK companies. This article addresses 8 critical success factors: *Complexity*, *compatibility*, *Relative advantage*, *top management support*, *firm size*, *technical readiness*, *competitive pressure*, *and trading partner pressure*.	Business Model Transformation; Cultural Change; Technology Acceptance.	Quantitative	MK	Cloud	• Estimate through real case scenarios whether Cloud Services are compatible with the current settings; • Apply the provided model including more Small sized PI firms; • Apply the provided model making cross-country comparisons.
Reinhardt et al., 2020	To represent current PI-DT Level of adoption, Planned Pathway, Future technology advancements.	Flexible and Agile Decision Making; Quality control and product design; Process Transparency; Workforce turnover; Cold Chain; Real-Time Monitoring.	Survey	MK	AR, VR, 3D, IoT, Cloud, Big Data, Cybersecurity	• Investigate Process Automation performance through DT technologies, avoiding siloed Technology/Process research; • Investigate through Technology Acceptance and Organizational Culture Literature the social and Individual's barriers to DT.
Nguyen et al., 2022	To represent the state of art, opportunities and challenges of Big Data Analytics in PI SC.	Shortage avoidance; Visibility and coordination improvement; SC Management; Inventory Management; Product Quality assurance; Sustainability.	Literature Review	SC, MA	Big Data, AI, Cloud	• Need for standardized data sharing protocols; • Address drug shortages and inventory management through forecasting demand models; • Use of Data Analytics to foster SC resilience;

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Table 2 (*continued*)

Paper	Research objectives and findings	Topics	Methodology	Value chain phase	Technology included in the study	Limitations and future research for PI-DT management
						• Investigate how to foster data sharing while ensuring regulatory compliance and data privacy; • To conduct Case Studies in the context of PI-SC to understand the main managerial and technological barriers for I4.0 tech adoption; • Shed light on how to match regulatory compliance with data usage.
Shamsuzzoha et al., 2020	This study found that implementing a centralized logistics system can have positive impacts on both the environment and the inbound processes.	SC Management; Enhanced Visibility.	Mixed Methods	SC	Big Data, Cloud	• To conduct comprehensive analysis of the inbound shipments and communication with other PI-SC partners.
R. Liu et al., 2021a	This study explores the current status of DT of sales in Japanese PI and identifies nine 9 initiatives: "*Creating Quality Patient Touch Points and Communication*," "*Responding to Changing Patient Demands*," "*Using Data and Information under Governance*," "*Analyzing Patient Data with AI*," "*Cross-functional Data Sharing*," "*Utilizing the Data Platform*," "*Cultivating Human Talent*," "*Changing Employees' Mindsets*," "*Exploring New Value Creation*."	Productive Process Reengineering; SC Management; Tracking, Transparency and Trust; Data Governance and Analytics; Scalability; Decision Making and Support; HR Management; Organizational Communication and Learning; Environmental; Impact on Patient; Regulatory Compliance; Social/ Governance.	Qualitative, Semi structured Interviews with Field Experts	MA	AI, Big Data	• More research analyzing DT of PI sales is needed, possibly, by extending this research with a more diversified sample, ranging from early to experienced DT adopters; • To build a digital maturity model based on these research findings to assess PI companies' capacity to engage the DT of sales.
Chen et al., 2020	This study aims to provide a detailed overview of Digital Twin's state of art and horizons in Pharma and Biopharma MK.	Real Time Monitoring; Agile and Flexible Decision Making; Business Model Transformation.	Literature Review	MK	Digital Twin, Cloud	• More investigations aiming at advanced data aggregation, mining, storage, and visualization methods; • Demonstrate the value of Real-Time monitoring for enhancing the PI regulatory approval process.
Wu and He, 2020	This study proposes and applies a framework to investigate the transfer of innovative drug discoveries from biopharma DIY labs to established PI R&D networks, with the ultimate goal of transforming them into marketable products.	Productive Process Reengineering; SC Management; Tracking, Transparency and Trust; Business Model Innovation; Data Governance and Analytics; Scalability; Decision Making and Support; Organizational Communication and Learning; Regulatory Compliance.	Qualitative, Case Study - Semi structured Interviews with Field Experts	DD	3D	• To analyze various innovation ecosystems in order to produce a broader range of evidence on the makeup of bio-PI innovation systems; • Conduct research on the links between the obstacles/facilitators and the innovative input of do-it-yourself (DIY) laboratories and development (R&D) networks.
Aquino et al., 2018	Investigating the future potential avenues of using 3D printing for personalized medicine.	Personalized Medicine; Customization; Rapid Prototypting; Product Quality.	Qualitative, Semi structured Interviews with Field Experts	DD, CT, MK, SC, MA	3D, AI	• Understanding levels of acceptance by Pharmacists, Physicians and Patients in using 3D printed drugs; • Addressing the benefits for Pharma manufacturers of abandoning standardized production of drug; • How 3D printings interact with Distribution, Logistics, and Warehouse Management.
Burrichter et al., 2022	To investigate how DT technologies interacts with HRM companies in PI for sustainable development.	Productive Process Reengineering; Data Governance and Analytics; Scalability; HR Management.	Quantitative	MA		• More investigation understanding the Role of AI for recruitment process.

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Table 2 (*continued*)

Paper	Research objectives and findings	Topics	Methodology	Value chain phase	Technology included in the study	Limitations and future research for PI-DT management
Solfa, 2022	To evaluate the impact of cybersecurity and SC risk management on digital operations. This paper identifies that (1) cybersecurity increases digital operations efficiency; (2) adopting digital operations allows to efficient SC risk management; and (3) cybersecurity allows to efficient SC risk management.	Maintenance and Monitoring; Productive Process Reengineering; Decision Making and Support.	Quantitative	MK, SC	Cybersecurity	• To replicate the research model across different geographical areas.
A. Sharma et al., 2020b	To represent IoT applications in SC and MK phases of PI.	Cold Chain Control; Product Quality; Lack of Transparency; Minimizing failure Costs of the equipment; Real-Time Monitoring; Warehouse Management; Drug Safety Assurance	Qualitative, Semi structured Interviews with Field Experts	MK, SC	IoT, AR, VR	• To address how IoT enhances patient satisfaction value using Big Data Analytics; • The interaction of Manual Labor, IoT, AR and VR.
M. Sharma et al., 2022	To investigate the barriers critical to PI industry 5.0 adoption and identify effective solution initiatives to overcome these barriers.	Productive Process Reengineering; Tracking, Transparency and Trust; Data Governance and Analytics; Scalability; Decision Making and Support; HR Management; Organizational Communication and Learning; Impact on Patient; Regulatory Compliance.	Mixed Methods	MK, SC, MA	IoT, Cloud, Big Data, Blockchain, Digital Twin, AI, Robot, AR, VR	• Further research may investigate, through quantitative analysis, the links between solution initiatives and the barriers identified in this paper; • This fieldwork was limited to German PI Experts, future research may extend the current framework to other countries.
Arief et al., 2022	This study aims to address the main competencies needed for PI-DT (critical thinking, bioinformatics, entrepreneurial thinking, digital skills, intrapreneurial skills, research skills, regulatory compliance, and data ethics) and digital levels (simplification, automatization, integrated system, digital transformation, disease prediction).	HR management, Technology Innovation Readiness; Regulatory compliance.	Mixed Methods	DD, CT, MK, SC, MA	IoT, Cloud, Big Data, Blockchain, AI, Robots, 3D, AR, VR	• Test research findings on a larger sample • Integrate research findings with HR practices; • To map PI-DT readiness on an international perspective.
Ding, 2018	To investigate the main opportunities and barriers to implement Industry 4.0 technologies and sustainable practices within PI SC.	SC Management, Sustainability; Training and Development; Quality Control and Safety; Advanced Technology; Precision Medicine.	Literature Review	MK, SC	IoT, Cloud, Big Data, 3D	• To conduct a Life Cycle Assessment (LCA) to demonstrate enhanced Inventory management performance, adjustment of production and optimization of MK operations; • Urge new regulations to accept new Industry 4.0 practices in Pharma; • New standardization of data sharing systems • Focus research on Social Impacts of PI-SC, by using organization behavior theories or tools such as "Social Life Cycle Assessment"; • To investigate how to enhance responsiveness of drug recall SC through cross-company symbiosis to reduce defected/counterfeited drug circulation; • To examine how smart logistics can improve sustainable and agile delivery service; • Have cross-country investigations about Hospital procurement; • Design appropriate Environmental, Social, and Governance (ESG)

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Table 2 (*continued*)

Paper	Research objectives and findings	Topics	Methodology	Value chain phase	Technology included in the study	Limitations and future research for PI-DT management
						indicators and assessment systems; • Review legal frameworks and regulations to integrate industry 4.0 technologies and sustainable practices.
Lima Jr et al., 2021	This study aims to identify the main challenges related to the PI-SC and its associated technological advances based on product characteristics, vehicle capabilities, and logistics service provider's expertise.	Maintenance and Monitoring; Organizational Communication and Learning; Impact on Patient.	Literature Review	SC	IoT, Big Data, Blockchain	• More research about the maintenance and logistic support in the Latin America Cold Chain; • Understanding the integration between IoT and Blockchain for effective SCM; • Deepening new regulation strategies to create incentives in using Dt technologies.
Argiyantari et al., 2020	To address Literature relating to the Lean principle application within PI-SC.	Maintenance and Monitoring; Productive Process Reengineering; Scalability; Decision Making and Support; HR Management; Organizational Communication and Learning; Regulatory Compliance.	Literature Review	SC, MK	IoT	• To investigate how IoT influences lean practices, concerning inventory control or Product visibility. A potential solution might be to conduct Action Research, since the scarcity of deployment of this research methodology.
Denicolai and Previtali, 2020	To understand key dimensions and discuss theoretical foundations of Business Model Transformation of PI companies because of Precision medicine.	Precision Medicine; Business Model Transformation; Patient Centered approaches; SC Management; CT Efficiency; Regulatory Compliance.	Qualitative, multiple case study	DD, MA, CT, SC	3D, Big Data, AI, IoT, Cloud	• More case studies engaging diversified companies in terms of capabilities and healthcare niche; • Verify through quantitative studies the theoretical contributions of this paper.
Kordestani et al., 2023	Collecting Knowledge of PI blockchains, identifying (1) features of smart contracts in the PI-SC, (2) role of smart contracts to fight counterfeited drugs, (3) Future research agenda.	Productive Process Reengineering; SC Management; Scalability; HR Management; Organizational Communication and Learning; Environmental; Impact on Patient; Regulatory Compliance; Social/ Governance.	Literature Review	SC, MA	Blockchain, IoT	• Further studies addressing the adoption of smart contract's potential against counterfeited drugs. • Need to design new protocols for safeguarding data safety and user's privacy; • To investigate how smart contracts create value for stakeholders such as patients, retailers, and manufacturers by removing intermediaries and enhancing visibility; • How smart contracts might reduce waste by enhancing visibility of SC.
Ramos et al., 2022	To establish 3D printing technology road mapping for the fields of DD and in vitro disease models. This research is of particular interest as it focuses on a startup company.	Bioprinting, Business Model Innovation; Crowdsourcing; Startup R&D	Qualitative, Case study	DD, CT	3D, IoT, AI, Robots	• Exploration of 3D printing R&D through crowdsourcing; • Multidisciplinary figures to integrate 3D printing in Drug and Discovery.
Saha et al., 2022	Adopting Emerging Technologies enhances Pharma SC Performance through the mediating effect of MK, distribution, and consumption processes.	Flexible and Agile Decision Making; Workforce turnover; Logistics and Procurement; Increasing Product Quality.	Quantitative	SC, MK	3D, IoT, Cloud, Blockchain, AI, Big Data	• To address AI deployment for Centralized or Decentralized SC; • Risk Identification across SC partners through AI; • To investigate how PI organizations can reach a Resilient Sustainability Performance (Integration with UN's SDGs Goals); • Engage studies in PI-organizations within developed countries.

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Table 2 (*continued*)

Paper	Research objectives and findings	Topics	Methodology	Value chain phase	Technology included in the study	Limitations and future research for PI-DT management
Kulkov, 2021	This study sheds the light on how AI influences and support for different business processes of PI companies.	Warehouse Management; Predictive Maintenance; Business Process Reengineering; HR; Patient Engagement.	Qualitative, Semi structured Interviews with Field Experts	DD, CT, MK, SC, MA	AR, VR, Robot, Big Data, AI	• Comparing AI application experience of other healthcare niches to assess opportunities for Business Model Transformation; • Need for more Case Studies dealing with AI and PI VCP; • How Venture Capitalism can influence AI based DD.
Kumar Detwal et al., 2023	To introduce a model for choosing vendor contract terms using machine learning specifically designed for direct drop-shipping within a worldwide omnichannel pharmaceutical supply chain.	Tracking, Transparency and Trust; Data Governance and Analytics; Real Time Monitoring; Agile and Flexible Decision Making; Business Model Transformation.	Quantitative	SC	AI, Big Data, Robot	• This model could be expanded upon to create a model for a supply chain network that manages order fulfillment via regional distribution centers. • This research was mainly focused on "Air Transportations"; future research could be further validated with Trucks, Rails, or waterways as other shipment modes.
M. Sharma et al., 2023	This article suggests a framework aiming to transition from I4.0 to Industry 4.0 + (I4.0+), highlighting the significance of collaboration between humans and machines. This collaboration is seen as pivotal in advancing towards sustainable supply chain management.	Predictive Maintenance; Quality control and product design; Maintenance and Monitoring; Productive Process Reengineering; Scalability; Decision Making and Support; Flexible and Agile Decision Making.	Qualitative, Semi structured Interviews with Field Experts	MK, SC	Big Data, Cloud, IoT, Blockchain, AI, Robots	• This article is based on expert opinions from India Practitioners, the generalizability of results should be tested across different countries. • Validate the developed Framework through cross-sectional and Longitudinal quantitative works.
Ertz et al., 2022	This article conducts a bibliometric and network analysis to explore how digital and sustainable technologies have influenced the cold chain sector.	Cold Chain Management; Logistics; Sustainability; Traceability; Energy Saving; Product Quality; Temperature Monitoring; IT infrastructure Renovation; Agile Decision Making; Decision Making and Support.	Bibliometric Analysis	SC	Blockchain, IoT, Big Data, Cybersecurity, AI, 3D	• This study is limited to Web of Science repository; future research should include other databases. • This investigation was focused mainly on Supply Chain and Logistics; future research should provide more comprehensive overview on the whole Pharmaceutical Value Chain.
Rathi et al., 2024	This Paper discussed how the Covid Pandemic enhanced the use of AI for Pharmaceutical Innovation.	Decision Making and Support; Regulatory Compliance; Impact on Patient; Patent Protection.	Quantitative	DD	AI	• Future researchers can further expand on this analysis to delve into the specific advantages or disadvantages associated with the growing utilization of AI.
Junaid et al., 2023	This research aims to investigate the interconnections between supply chain dynamic capabilities, supply chain integration, supply chain resilience, sustainable competitive advantage, and sustainable supply chain performance.	Supply Chain Resilience; Sustainability; Environmental Performance; Decision Making and Support; Flexible and Agile Decision Making.	Quantitative	SC	AI, Big Data, IoT, Blockchain, Cloud	• This Paper's outcomes are limited on Pakistan's data; future research may conduct comparative analysis between Developed and Underdeveloped Countries' performance. • This study limits its focus on only three elements—sensing, learning, and coordinating—as part of the supply chain dynamic capability, which provides supply chain visibility. Future research could broaden this scope by incorporating additional factors, such as integration, into the pool of supply chain dynamic capabilities.

Abbreviations: Drug Development (DD), Clinical Trials (CT), Manufacturing (MK), Supply Chain (SC), Market Access (MA), Pharmaceutical Industry (PI), Digital Transformation (DT), Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), Internet of Things (IoT).

methodologies to investigate PI-DT. It is worth highlighting that a substantial portion of management studies utilize qualitative methods, accounting for 40 % of the total review framework. These qualitative approaches encompass various techniques, such as single case studies, multiple case studies, exploratory research, and a considerable number of semi-structured interviews conducted with field experts. This notable emphasis on qualitative methodologies underscores a strong commitment to comprehending the experiences, attitudes, and perceptions of individuals actively engaged in PI-DT. The review framework further reveals that Literature Reviews constitute the second most used methodology, accounting for 23 % of the total aggregate. The Literature review approach is valuable in identifying gaps and opportunities for further investigations. However, the few articles addressing insights from such studies only partially address the PI-DT, as they tend to be confined to isolated boxes, eighter to single VCP or digital technology, lacking a comprehensive insight of the phenomenon. In conclusion, Quantitative methods, Mixed Methods, Surveys and Bibliometric Analysis are underutilized (17 %, 9 %, 3 %, 3 %), indicating less emphasis on these methodologies.

Based on the review framework, PI-DT is being researched across the whole VCP. The two most cited VCP are *SC* and *MK*, consisting respectively in 66 % and 46 % of the reviewed papers. These two VCP are cited together in 42 % of the review framework, evidencing an interesting association of these VCP for researchers. Additionally, 40 % of the papers concentrate on the MA phase, implying that researchers are increasingly interested in this topic. Finally, 20 % of the papers are focused on the CT phase and 17 % on the DD phase. This suggests a growing interest in DT, but more studies are needed to thoroughly address the enabled digital technology's positive and negative effects on these phases.

The review framework presents the prevalence of various digital technologies contributing to PI-DT. IoT and AI appear to be highly significant, mentioned in 54 % and 51 % of the articles. This indicates a substantial focus on interconnected devices and data analytics, improving operational efficiencies within PI VCP, possibly for monitoring, data collection, or process optimization (Patel and Shah, 2022; D. K. Sharma et al., 2020a; Hariry et al., 2022). Big Data follows closely behind at 46 %, indicating a considerable emphasis on handling and deriving insights from vast volumes of data in pharmaceutical research, development, and decision-making processes (Banner et al., 2021). Furthermore, Cloud technology (37 %) and Blockchain (37 %) both show a considerable presence. Cloud computing likely plays a role in data storage, accessibility, and collaboration (Reinhardt et al., 2020), while Blockchain might be utilized for enhancing transparency, security, and traceability in the pharmaceutical supply chain or clinical trials (Omar et al., 2021). In addition, 3D technology (29 %), AR (Augmented Reality) (20 %), and VR (Virtual Reality) (20 %) seem to be moderately represented. These technologies might be used in drug modeling, training simulations, or even patient education and engagement (Trenfield et al., 2022; Awad et al., 2018). Last, Cybersecurity (11 %) and Digital Twin (9 %) appear less frequently, suggesting potentially less emphasis on ensuring robust cybersecurity measures and implementing Digital Twin technologies within the pharmaceutical sector (Chen et al., 2020), at least in the context of the articles reviewed.

Overall, this data indicates a widespread integration of various digital technologies in the pharmaceutical industry, with IoT, AI, Big Data, Cloud, and Blockchain being particularly prominent. This integration reflects a concerted effort to innovate, improve processes, and advance research and development within the pharmaceutical landscape.

4. Review framework

Table 2 provides a comprehensive overview of the review framework, addressing Research Objectives and Findings, Methodology, Value Chain Phase, Technology included and Limitations and Future research for PI-DT Management research.

5. Future research agenda

After conducting an in-depth analysis of the review framework, four crucial research areas that hold significant relevance to the PI-DT context were identified. These areas include (I) *Operations Management Research*, (*II*) *Strategic Management Research*, (*III*) *Organization's Theory Research*, and (*IV*) *Stakeholder Management Research*. These research areas have a strong connection with all the DT technologies, and profound influence on critical aspects of drug's value chain phases. In the next paragraphs, a new research agenda, technologies involved, VCP, relevant literature, and viable research questions is presented.

5.1. Operations management research

The first research area that emerged from the review framework is (I) *Operations Management Research*, which involves the design, planning, and control of processes and systems to deliver drugs effectively and efficiently to stakeholders (Slack et al., 2010). The research agenda of this study encompasses a series of related topics to be advanced in the upcoming years of research, considering the following Macro-areas: (*a*) *Maintenance and Monitoring of Equipment*, (*b*) *Productive Process Reengineering*, (*c*) *Supply Chain Management*, (*d*) *Tracking, Transparency and Trust*, which have not been comprehensively detailed so far, specifically focusing on leveraging digital technologies for: (a.1) Predictive Maintenance, (a.2) Process Visualization and Simulation, (a.3) Product Quality Control, (a.4) Real-Time Monitoring; (b.1) Business Process Management, (b.2) Flexible and Agile Production Lines, (b.3) Manual Work Reduction, (b.4) Production Lead Time, (b.5) Reduced Bureaucracy (b.6); Centralized and Decentralized Supply Chain, (c.1) Inventory Management, (c.2) Logistics Management, (c.3) Supply Chain Resilience, (d.1) Track of Products and Material's Procurement, (d.2) Cold Chain Control Monitoring, (d.3) Lack of Transparency, and (d.4) Lack of Trust. Overall, the research agenda outlined aligns with *Operations Management Research* principles by seeking to optimize processes, improve quality, and enhance supply chain coordination through the integration of new technologies. Future research should therefore address the unique challenges faced by the PI and related new streams of research in the literature, as indicated in Table 3.

5.2. Strategic management research

The second area that emerged from is *Strategic Management Research*, which involves the formulation and implementation of strategies to achieve organizational goals competitive advantage and superior performance (Durand et al., 2017). To this account, the rapidly evolving pharmaceutical landscape, by integrating digital technologies offers significant opportunities for organizations. The research agenda of this study encompasses a series of related topics to be advanced in the upcoming years of research, considering the following Macro-areas: (a) *Business Model Innovation* (*b*) *Data Governance and Analytics*, and (*c*) *Scalability*, which have not been comprehensively detailed so far, specifically focusing on leveraging digital technologies for: (a.1) New Marketing Channels, (a.2) New Value Creation, (a.3) Need of New Business Models, (a.4) Smart Contracts; (b.1)Patient Retention, (b.2) Data Accessibility, Governance, Transparency, Mining and Demand, (b.3) Forecasting production to Demand, Sales and Profits (b.4) Risk management; (c.1) Venture Capitalism, Startup financing and acquisition, (c.2) Lack of Strategic Guidance over digital innovation. Overall, the review framework emphasized the need for more comprehensive

Table 3
Future research agenda for the Operations Management Research area.

Research topic	Aggregated area	Possible related technologies	Value chain	Literature	Research questions
Predictive maintenance	Maintenance and Monitoring	AI, IoT	MK, SC	Kulkov, 2021; Silva et al., 2020; Reinhardt et al., 2020; Bamakan et al., 2021; A. Sharma et al., 2020b; Coito et al., 2022; Arief et al., 2022; Lima Jr et al., 2021; M. Sharma et al., 2023; Ding, 2018	• How can AI and IoT-based predictive maintenance impact the reduction of downtime, maintenance costs, and equipment failure rates in pharmaceutical manufacturing operations? • How can AI and IoT-based predictive maintenance systems enable proactive identification of potential risks and deviations in supply chain operations to ensure product safety and integrity?
Process Visualization and simulation	Maintenance and Monitoring	Digital Twins, AR, VR, AI	MK	Chen et al., 2020; Coito et al., 2022; Kumar Detwal et al., 2023; M. Sharma et al., 2023; Ertz et al., 2022	• How can AR and VR technologies be utilized to improve training, process monitoring, and decision-making in pharmaceutical manufacturing? • How can process visualization and simulation, augmented by AI, AR, VR and Digital Twin technologies, support quality control, regulatory compliance, and risk management in pharmaceutical manufacturing?
Product Quality Control	Maintenance and Monitoring	AI, Digital Twins, Blockchain, IoT, 3D, Big Data	MK, SC	Kulkov, 2021; Chen et al., 2020; Zakari et al., 2022; Saha et al., 2022; Silva et al., 2020; Hosseini Bamakan et al., 2021; A. Sharma et al., 2020b; Aquino et al., 2018; Ding, 2018; Coito et al., 2022; Arief et al., 2022; Shahzeb Zulfiqar et al., 2022; Lima Jr et al., 2021; Alharthi et al., 2020; Argiyantari et al., 2020; M. Sharma et al., 2023; Ertz et al., 2022; Nguyen et al., 2022	• How can big data analytics and advanced statistical techniques be applied to large-scale quality control data sets in the pharmaceutical industry, leading to improved process optimization and defect detection?
Real-Time Monitoring	Maintenance and Monitoring	Blockchain, AI, IoT, Digital Twins	CT, MK, SC	Kulkov, 2021; Chen et al., 2020; Silva et al., 2020; A. Sharma et al., 2020b; Ding, 2018; Arief et al., 2022; M. Sharma et al., 2022; Lima Jr et al., 2021; Kordestani et al., 2023; Del and Solfa, 2022; Reinhardt, Oliveira, and Ring 2020; Kumar Detwal et al., 2023; M. Sharma et al., 2023; Ertz et al., 2022; Junaid et al., 2023	• How can real-time monitoring systems enhance the agility and responsiveness of the pharmaceutical supply chain, enabling faster decision-making, reduced lead times, and improved user's satisfaction? • Can IoT and AI deployment improve clinical trials efficiency through Blockchain based data protection?
Business Process Management	Productive Process Reengineering	Digital Twins, AI, Big Data, VR, AR, AI, Cloud, Digital Twins, 3D	DD, CT, MK, SC	Satwekar et al., 2022; Kulkov, 2021; Festa et al., 2018; Burrichter et al., 2022; Ghadge et al., 2022; Argiyantari et al., 2020; Chen et al., 2020; Aquino et al., 2018; Wu and He, 2020; Kumar Detwal et al., 2023; M. Sharma et al., 2023; Ertz et al., 2022; Junaid et al., 2023	• How can cloud computing adoption improve communication, coordination and efficiency of manufacturing activities?
Flexible and Agile production lines	Productive Process Reengineering	IoT, AI, VR, AR, 3D	MK, MA	Chen et al., 2020; Aquino et al., 2018; Ding, 2018; M. Sharma et al., 2022; Kumar Detwal et al., 2023; Ertz et al., 2022; Junaid et al., 2023	• How do flexible and agile production systems impact supply chain coordination, responsiveness, and customer satisfaction, particularly in adjusting production to meet dynamic market demands?
Manual Work Reduction	Productive Process Reengineering	Robots, AI, AR, VR, IoT, Digital Twins	MK	Kulkov, 2021; Silva et al., 2020; Sharma et al., 2020b; Coito et al., 2022; M. Sharma et al., 2023	• How to evaluate IoT effectiveness in reducing manual interventions, optimizing the utilization of equipment and resources in pharmaceutical production lines?
Production Lead Time	Productive Process Reengineering	AI, IoT, 3D	MK	Kulkov, 2021; Silva et al., 2020; Sharma et al., 2020b; Aquino et al., 2018	• How can digital process automation and workflow optimization, utilizing AI and IoT technologies, contribute to the reduction of lead time and increase agility in pharmaceutical manufacturing?
Reduced Bureaucracy	Productive Process Reengineering	AI, Cloud, Blockchain	MK, MA	Kulkov, 2021; Zakari et al., 2022; Silva et al., 2020; Alharthi et al., 2020	• What are the key bureaucratic challenges and bottlenecks faced in the manufacturing phase of the pharmaceutical value chain, and how can digital technologies be leveraged to mitigate these challenges? • How can cloud-based solutions facilitate collaboration and information sharing among different stakeholders in the pharmaceutical value chain to reduce bureaucracy and enhance operational efficiency? • How can regulatory frameworks and policies be adapted to foster the digital transformation of pharmaceutical manufacturing and effectively address potential challenges related to reduced bureaucracy?

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Table 3 (*continued*)

Research topic	Aggregated area	Possible related technologies	Value chain	Literature	Research questions
Centralized and Decentralized SC	Supply Chain Management	3D, IoT, Cloud, Blockchain, AI, Big Data	SC	Saha et al., 2022; Shamsuzzoha et al., 2020; Kumar Detwal et al., 2023; M. Sharma et al., 2023; Junaid et al., 2023	• What are the key advantages and disadvantages of implementing a centralized supply chain model in the pharmaceutical industry, and how does it impact operational efficiency and cost-effectiveness in other phases? • What are the critical success factors for transitioning from a traditional decentralized supply chain model to a centralized model in the pharmaceutical industry, and how can organizations effectively manage this transition?
Inventory Maanagement	Supply Chain Management	VR, AI, AR, 3D, Big Data, Cloud, Robots, IoT	MK, SC	Kulkov, 2021; Saha et al., 2022; Ding, 2018; Nguyen et al., 2022; Lima Jr et al., 2021; Kordestani et al., 2023; Argiyantari et al., 2020; Reinhardt et al., 2020; Sharma et al., 2020b; Aquino et al., 2018; Nguyen et al., 2022; Arief et al., 2022; Solfa 2022; Kumar Detwal et al., 2023; Ertz et al., 2022; Junaid et al., 2023	• How can cloud-based inventory management systems enhance data accessibility, collaboration, and decision-making efficiency across the pharmaceutical manufacturing and supply chain operations? • What are the critical success factors for implementing inventory visibility and synchronization initiatives across multiple stakeholders in the pharmaceutical supply chain? • How can inventory management practices be aligned with sustainability goals in the pharmaceutical industry, considering factors such as reducing waste, optimizing transportation, and minimizing environmental impact? • How can AR and VR technologies be utilized to optimize warehouse layout and design in the pharmaceutical industry, considering factors such as reduction of manual labor, space utilization, inventory management, and picking efficiency? • What are the environmental sustainability implications of digital warehouse management technologies in the pharmaceutical industry, and how can organizations measure and minimize their carbon footprint and waste generation?
Logistics Management	Supply Chain Management	AI, Blockchain, IoT	SC	Kulkov, 2021; Zakari et al., 2022; Saha et al., 2022; Aquino et al., 2018; Ding, 2018; Nguyen et al., 2022; Zulfiqar et al., 2022; Lima Jr et al., 2021; Argiyantari et al., 2020; M. Sharma et al., 2023; Ertz et al., 2022; Junaid et al., 2023	• How can AI algorithms and machine learning techniques be utilized to optimize route planning, transportation scheduling, and resource allocation in pharmaceutical logistics operations? • What are the implications of adopting autonomous vehicles, drones, and robotics technologies in last-mile delivery and distribution processes within the pharmaceutical logistics context? • What are the critical success factors for implementing green and sustainable practices in pharmaceutical logistics, including reducing carbon emissions, optimizing packaging materials, and minimizing waste generation?
Supply Chain Resilience	Supply Chain Management	Blockchain	SC	Saha et al., 2022; Solfa, 2022; Kumar Detwal et al., 2023; Ertz et al., 2022; Junaid et al., 2023	• How can supply chain resilience be enhanced through the adoption of Blockchain? • What are the implications of adopting blockchain-based smart contracts and decentralized platforms for enhancing trust, transparency, and collaboration among supply chain partners in the pharmaceutical industry? • What are the key performance indicators and metrics for measuring and benchmarking supply chain resilience in the pharmaceutical industry, and how can organizations track and evaluate their progress towards achieving resilience goals?
Track of Products and Material's Procurement	Tracking, Transparency and Trust	AI, IoT, Blockchain, Cloud	SC, MK	Sharma et al., 2020b; Ding, 2018; Arief et al., 2022; Zulfiqar et al., 2022; Lima Jr et al., 2021; Solfa, 2022; Satwekar et al., 2022; Kulkov, 2021; Chen et al., 2020; Saha et al., 2022; Shamsuzzoha et al., 2020;	• What are the potential applications of blockchain technology in enhancing transparency, traceability, and security in material procurement and supplier's verification?

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Table 3 (*continued*)

Research topic	Aggregated area	Possible related technologies	Value chain	Literature	Research questions
				Denicolai and Previtali, 2020; M. Sharma et al., 2022; Zakari et al., 2022; Zulfiqar et al., 2022; Ghadge et al., 2022; Hosseini Bamakan et al., 2021; Nguyen et al., 2022; Ertz et al., 2022; Junaid et al., 2023	• What are the key challenges and opportunities in utilizing predictive analytics models to optimize procurement decision-making, including strategic sourcing, order quantity determination, and lead time management in the pharmaceutical supply chain?
Cold Chain Control Monitoring	Tracking, Transparency and Trust	Blockchain, IoT	SC	(Zakari et al., 2022) (Hosseini Bamakan et al., 2021) (Sharma et al., 2020b) (Ding, 2018) (Lima Jr et al., 2021) (Ghadge et al., 2022) (Argiyantari et al., 2020) (Solfa, 2022) (Shamsuzzoha et al., 2020) (Alharthi et al., 2020) (Ghadge et al., 2022) (Kulkov, 2021) (Saha et al., 2022) (M. Sharma et al., 2023) (Ertz et al., 2022)	• How can IoT devices and sensors be integrated into Cold Chain of biological systems to enable real-time tracking and monitoring of products, temperature-sensitive items, and inventory levels? • What are the critical success factors and best practices for implementing a robust cold chain control system that ensures compliance with regulatory requirements, reduces waste due to expired products, and maintains product quality and efficacy throughout the supply chain?
Lack of Transparency	Tracking, Transparency and Trust	Blockchain, IoT, Big Data	SC	Zakari et al., 2022; Sharma et al., 2020b; Ding, 2018; Nguyen et al., 2022; Shamsuzzoha et al., 2020; Kordestani et al., 2023; Solfa, 2022; Alharthi et al., 2020; Ghadge et al., 2022	• How can IoT and sensor technologies be utilized to capture and collect real-time data in the pharmaceutical supply chain, enabling improved visibility, accountability, and transparency in the movement and storage of products? • How can collaborative platforms and information sharing systems be designed and implemented to facilitate transparency and trust among supply chain partners in the pharmaceutical industry, considering the sensitivity and confidentiality of health information?
Lack of Trust	Tracking, Transparency and Trust	Blockchain	SC	Zakari et al., 2022; M. Sharma et al., 2022; Ertz et al., 2022	• How can blockchain technology be utilized to enhance trust and security in the pharmaceutical supply chain, particularly in ensuring the integrity of product information, verifying the authenticity of drugs, and facilitating transparent transactions between supply chain partners? • How can smart contract technology be integrated into the pharmaceutical supply chain to automate trust-based processes, such as verification of product provenance, compliance with regulations, and execution of contractual agreements between stakeholders?

Abbreviations: Drug Development (DD), Clinical Trials (CT), Manufacturing (MK), Supply Chain (SC), Market Access (MA), Pharmaceutical Industry (PI), Digital Transformation (DT), Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), Internet of Things (IoT).

studies in the PI-DT Strategic Management Research field, that future researchers shall pursue, as indicated in Table 4.

5.3. Organization's theory research

The third area is related to *Organization Theory Research*, which seeks to understand and analyze how organizations function, evolve, and adapt to changes in their external environment (Wilden et al., 2019). The identified research agenda aligns with the field of Organization Theory, examining the impact of digital technologies on (a) *Decision Making and Support*, (b) *HR Management*, and (c) *Organizational Communication and Learning*, which has not been comprehensively detailed. More specifically, the examination focuses on leveraging digital technologies for: (a.1) Agile Decision Making, (a.2) Project Lifecycle monitoring; (b.1) the Need for new Multidisciplinary Figures and Digital trainings, (b2) Workforce Turnover and Recruitment; (c.1) Cultural Change and Technology Acceptance, (c.2) Interoperability, Obsolescent IT Infrastructures, and inefficient Information sharing across Functions, (c.3) Managerial Awareness and Leadership, (c.4) Organizational Readiness for innovation. Overall, the research agenda aligns with the principles of Organization Theory by focusing on the impact of digital transformation on various aspects of organizational functioning and addressing key challenges and opportunities in adapting to the digital landscape within the pharmaceutical industry. Future research shall therefore pursue these research streams, as indicated in Table 5.

5.4. Stakeholder's theory research

The fourth area is Stakeholder's Research, identifying PI organizations as responsible agents for a wide range of stakeholders and focusing on the integration of digital technologies for triggering different impacts (Matten and Moon, 2004) on: (a) the *Environment*, (b) *Patients*, (c) *Regulatory Institutions*, (d) *Governance*, (e) *Society* which have not been comprehensively examined. More specifically, the framework highlights: (a.1) the environmental footprint, (a.2) sustainability certifications, (b.1) Customization, Personalization, and Precision Medicine, (b.2) Ensuring Drug Safety, Counterfeit Drug Prevention, and Higher Accessibility to Drugs, (c.1) Data Transparency for Regulatory Validation, (c.2) Enhanced adherence to Regulatory standards, (c.3) Need for standardized data sharing protocols and Updated Regulatory Frameworks, (d.1) Eliminating Discrimination in recruitment, (d.2) Patient-Data Security and Privacy, and (e.1) University Education Gap. Accordingly, future research should pursue these research streams, as indicated in Table 6.

Table 4
Future research agenda for the Strategic Management Research area.

Research topic	Aggregated area	Possible related technologies	Value chain	Literature	Research questions
New Marketing Channels	Business Model Innovation	AI, Big Data	MA	Kulkov, 2021; Liu et al., 2021a; Kumar Detwal et al., 2023; Junaid et al., 2023	• How can the integration of AI and big data analytics enable pharmaceutical companies to identify and target new customer segments through personalized marketing strategies? • What are the potential risks and challenges associated with adopting new marketing channels driven by AI and big data, and how can organizations mitigate these risks while maximizing the overall performance? • How do the regulatory and legal frameworks impact the adoption and implementation of AI-driven marketing channels in the pharmaceutical industry, and what strategies can organizations employ to navigate these complexities?
New Value Creation	Business Model Innovation	Digital Twins, AI, Big Data, VR, AR, AI, Cloud, Digital Twins, 3D	DD, CT, MK, SC, MA	Saha et al., 2022; Satwekar et al., 2022; Kulkov, 2021; Silva et al., 2020; Denicolai and Previtali, 2020; Ramos et al., 2022; Liu et al., 2021a, 2021b; Festa et al., 2018; Burrichter et al., 2022; Ghadge et al., 2022; Argiyantari et al., 2020; Chen et al., 2020; Aquino et al., 2018; Wu and He, 2020; M. Sharma et al., 2023; Ertz et al., 2022; Rathi et al., 2024	• What are the key challenges and opportunities associated with integrating AI, big data, and advanced analytics into clinical trial processes, and how can organizations leverage these technologies to enhance patient recruitment, trial design, and overall trial efficiency for a competitive edge? • How can the implementation of digital technologies such as AI, VR, and AR revolutionize manufacturing processes in the pharmaceutical industry, improving productivity, quality control, and supply chain integration to achieve superior performance? • What are the implications of business process transformation and the adoption of digital technologies on market access strategies, pricing models, and reimbursement negotiations in the pharmaceutical industry, and how can organizations align these processes to secure a competitive position in the market?
Need of New Business Model	Business Model Innovation	IoT, 3D, AI, Blockchain, Big Data, Digital Twins	MA, MK, SC, DD, CT	Denicolai and Previtali, 2020; Al-Shura et al., 2018; Wu and He, 2020; Liu et al., 2021a, 2021b; Ghadge et al., 2022; Kumar Detwal et al., 2023; Rathi et al., 2024	• Does digital technology deployment enhance business performance through Sustainable business model innovation? • What are the implications of incorporating sustainability considerations into business model innovation, and how can organizations balance environmental, social, and economic factors to create sustainable value propositions that differentiate them in the market and drive competitive advantage?
Smart contracts	Business Model Innovation	Blockchain	SC	Ghadge et al., 2022; Hosseini Bamakan et al., 2021; Ding, 2018; Kordestani et al., 2023	• How can smart contracts facilitate the automation and streamlining of compliance and regulatory requirements in the pharmaceutical supply chain, ensuring adherence to quality standards and regulatory frameworks? • How can smart contracts facilitate the implementation of sustainable and responsible sourcing practices in the pharmaceutical supply chain, ensuring ethical procurement and fair trade, and how can organizations leverage this to differentiate themselves and achieve superior peerformance?
Patient Retention	Data Governance and Analytics	AI, Big Data	MA	Kulkov, 2021; Liu et al., 2021a, 2021b	• How can personalized medicine and targeted interventions supported by AI and big data analytics improve patient adherence to treatment regimens and increase overall patient retention rates? • How can pharmaceutical companies leverage digital channels, such as social media and online communities, to engage and connect with patients, creating a sense of belonging and fostering a patient community that enhances patient retention and superior performance?

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Table 4 (*continued*)

Research topic	Aggregated area	Possible related technologies	Value chain	Literature	Research questions
Data Accessibility, Governance, Transparency, Mining and Demand of Data	Data Governance and Analytics	Blockchain, AI, Big Data,	MK, SC, MA	Kulkov, 2021; Zakari et al., 2022; Silva et al., 2020; Sharma et al., 2020b; Nguyen et al., 2022; Liu et al., 2021a, 2021b; Kumar Detwal et al., 2023; Rathi et al., 2024	• How can data mining and analytics be employed to identify inefficiencies and bottlenecks in pharmaceutical manufacturing processes, supply chain operations, and market access strategies, allowing companies to optimize resource allocation, reduce costs, and improve speed to market, thereby gaining a competitive advantage? • What are the barriers and enablers to data sharing and collaboration among different stakeholders in the pharmaceutical industry, and how can innovative data-sharing platforms and incentives be designed to foster collaboration, knowledge exchange, and collective learning, driving a superior performance for all parties involved?
Forecasting production to Demand, Sales and Profits	Data Governance and Analytics	AI, Big Data, Digital Twins, IoT	MK, SC, MA	Kulkov, 2021; Saha et al., 2022; Liu et al., 2021a, 2021b; Satwekar et al., 2022; Chen et al., 2020; Kumar Detwal et al., 2023; M. Sharma et al., 2023; Ertz et al., 2022	• What are the key challenges and opportunities in integrating real-time data from IoT devices and digital twins into production forecasting models, and how can the utilization of such data sources enhance the accuracy and timeliness of production forecasts, leading to improved profitability and a competitive edge in the market? • What are the key success factors in developing collaborative forecasting models and platforms that enable cross-functional collaboration and information sharing among different stakeholders, such as manufacturers, distributors, and healthcare providers, to improve forecasting accuracy and gain a competitive edge through improved supply chain coordination?
Risk Management	Data Governance and Analytics	AI, Digital Twin, Blockchain, IoT	SC, MK	Zakari et al., 2022; Zulfiqar et al., 2022; M. Sharma et al., 2022; Kumar Detwal et al., 2023; Junaid et al., 2023	• What are the key challenges and opportunities in integrating digital twin technology into risk management practices in the pharmaceutical industry? • How can digital twins enhance risk assessment, monitoring, and mitigation strategies, ultimately enabling companies to achieve higher levels of resilience, agility, and competitive advantage? • How can predictive analytics and machine learning algorithms be employed to forecast and prioritize risks in pharmaceutical manufacturing and supply chain operations, enabling companies to allocate resources effectively, optimize risk response strategies, and gain a competitive edge through improved risk-informed decision-making?
Venture Capitalism, Startup financing and acquisition	Scalability	IoT, Cloud, Big Data, Blockchain, AI, Robots, 3D, AR, VR	DD, CT, MK, SC, MA	Arief et al., 2022; Kulkov, 2021; Ramos et al., 2022; Wu and He, 2020; Liu et al., 2021a, 2021b	• How does the availability of venture capital funding impact the success and growth of digital health startups in the pharmaceutical industry? • How can pharmaceutical companies strategically leverage venture capitalist partnerships to gain a competitive advantage in accessing innovative technologies and driving digital transformation across the value chain?
Lack of Strategic Guidance over digital innovation	Scalability	IoT, Cloud, Big Data, Blockchain, AI, Robots, 3D, AR, VR	DD, CT, MK, SC, MA	Satwekar et al., 2022; Kulkov, 2021	• What are the mechanisms and frameworks for assessing the potential impact and scalability of digital innovation initiatives in the pharmaceutical industry, and how can companies evaluate and prioritize investment opportunities to ensure strategic alignment and long-term competitive advantage?

Abbreviations: Drug Development (DD), Clinical Trials (CT), Manufacturing (MK), Supply Chain (SC), Market Access (MA), Pharmaceutical Industry (PI), Digital Transformation (DT), Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), Internet of Things (IoT).

Table 5
Future research agenda for the Organization's Theory Research area.

Topic	Aggregated area	Possible related technologies	Value chain	Literature	Research questions
Agile Decision Making	Decision Making and Support	AI, Big Data, IoT	DD, CT, MK, SC, MA	Kulkov, 2021; Silva et al., 2020; Wu and He, 2020; Liu et al., 2021a, 2021b; Satwekar et al., 2022; Kumar Detwal et al., 2023; M. Sharma et al., 2023; Ertz et al., 2022; Junaid et al., 2023	• What role does AI based decision-making play in optimizing the supply chain of pharmaceutical industry? • How can technologies such as AI, big data, and IoT be leveraged to support real-time decision-making, reduce lead times, and improve inventory management?
Process Lifecycle monitoring	Decision Making and Support	IoT, AI, Big Data, Cloud	MK, SC	Satwekar et al., 2022; M. Sharma et al., 2022; Liu et al., 2021a, 2021b; Ghadge et al., 2022; M. Sharma et al., 2023	• What are the key success factors for implementing cloud-based project life-cycle monitoring systems in the pharmaceutical industry? • How does the adoption of cloud technologies influence organizational change in terms of collaboration, data accessibility, and scalability?
Need of new Multidisciplinary Figures and digital trainings	HR Management	IoT, Cloud, Big Data, Blockchain, AI, Robots, 3D, AR, VR, Digital Twins	DD, CT, MK, SC, MA	Reinhardt et al., 2020; Arief et al., 2022; Liu et al., 2021a, 2021b; Ding, 2018; Denicolai and Previtali, 2020; Arief et al., 2022; Ramos et al., 2022; Al-Shura et al., 2018; Zulfiqar et al., 2022; M. Sharma et al., 2022; Wu and He, 2020; Burrichter et al., 2022	• What are the challenges, barriers, risks and benefits in implementing new multidisciplinary roles and responsibilities in the pharmaceutical industry's digital transformation? • How can pharmaceutical organizations address these challenges to drive successful organizational change? • How can organizations foster a culture of continuous learning and adaptability through training initiatives to support the digital transformation of the pharmaceutical industry? • How can organizations tailor training programs to address the specific needs and roles within pharmaceutical Value Chain?
Workforce Turnover and Recruitment	HR Management	AI, Robots	DD, CT, MK, SC, MA	Kulkov, 2021; Saha et al., 2022; Silva et al., 2020; Arief et al., 2022; M. Sharma et al., 2022; Burrichter et al., 2022; Satwekar et al., 2022; Alharthi et al., 2020; Reinhardt et al., 2020	• How does the reduction of manual work through the implementation of robotic systems and automation technologies impact workforce dynamics, skill requirements, and job roles in pharmaceutical manufacturing? • What are the ethical barriers, benefits and challenges of deploying AI for the recruiting process?
Cultural Change and Technology Acceptance	Organizational Communication and Learning	IoT, Cloud, Big Data, Blockchain, AI, Robots, 3D, AR, VR, Digital Twins	DD, CT, MK, SC, MA	Saha et al., 2022; Silva et al., 2020; Aquino et al., 2018; Ding, 2018; Denicolai and Previtali, 2020; Arief et al., 2022; Al-Shura et al., 2018; Zulfiqar et al., 2022; Liu et al., 2021a, 2021b; Ghadge et al., 2022; Argiyantari et al., 2020; Solfa, 2022; Alharthi et al., 2020; Liu et al., 2021a, 2021b; Argiyantari et al., 2020	• What are the key cultural and individual's barriers and challenges that organizations face when implementing digital technologies? • How can organizations effectively communicate the purpose and benefits of the digital transformation to employees across different phases of the pharmaceutical value chain and drive cultural change and technology acceptance? • How do cultural differences across geographies and functional areas within the pharmaceutical industry influence the digital transformation process, cultural change, and technology acceptance? How can organizations effectively manage these differences? • How can organizations measure and assess the progress and impact of cultural change initiatives during the digital transformation of the pharmaceutical industry, and what are the key indicators of successful cultural change in this context?
Interoperability, Obsolescent IT Infrastructures, and inefficient Information sharing across Functions	Organizational Communication and Learning	IoT, Cloud, Big Data, Blockchain, AI, Robots, 3D, AR, VR, Digital Twins	DD, CT, MK, SC, MA	Saha et al., 2022; Liu et al., 2021a, 2021b; Silva et al., 2020; Arief et al., 2022; Wu and He, 2020; Kordestani et al., 2023; Alharthi et al., 2020; Ghadge et al., 2022; Chen et al.,	• How does inefficient information sharing impact decision-making processes and overall performance across different functions within the pharmaceutical industry, and what digital technology can

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Table 5 (*continued*)

Topic	Aggregated area	Possible related technologies	Value chain	Literature	Research questions
				2020; Reinhardt et al., 2020; Ertz et al., 2022	be employed to enhance information flow and knowledge sharing? • How does the lack of interoperability and outdated IT infrastructures affect communication, collaboration, and knowledge sharing across different phases of the pharmaceutical value chain?
Managerial Awareness and Leadership	Organizational Communication and Learning	IoT, Cloud, Big Data, Blockchain, AI, Robots, 3D, AR, VR, Digital Twins	DD, CT, MK, SC, MA	Denicolai and Previtali, 2020; Arief et al., 2022; Al-Shura et al., 2018; Zulfiqar et al., 2022; Wu and He, 2020; Alharthi et al., 2020; Liu et al., 2021a, 2021b; Ghadge et al., 2022; Satwekar et al., 2022	• What role does leadership play in shaping and driving cultural change during the digital transformation of the pharmaceutical industry, and how can leaders effectively inspire employees through the change process?
Organizational Readiness to innovation	Organizational Communication and Learning	IoT, Cloud, Big Data, Blockchain, AI, Robots, 3D, AR, VR, Digital Twins	DD, CT, MK, SC, MA	Satwekar et al., 2022; Alharthi et al., 2020; M. Sharma et al., 2022; Kulkov, 2021; Aquino et al., 2018	• What strategies can be employed to manage the transition from legacy systems to interoperable platforms and minimize disruption to ongoing operations, while maximizing the benefits of digital transformation across the value chain phases? • How can organizations assess their current level of readiness for digital innovation and identify areas of improvement across the value chain phases?

Abbreviations: Drug Development (DD), Clinical Trials (CT), Manufacturing (MK), Supply Chain (SC), Market Access (MA), Pharmaceutical Industry (PI), Digital Transformation (DT), Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), Internet of Things (IoT).

6. Implications for theory and practice

This systematic literature review on the digital transformation (DT) of the pharmaceutical industry (PI) from a management studies perspective enriches theoretical frameworks in several ways.

The literature review underscores a critical gap in the comprehensive understanding of DT's implications within the PI, particularly from a management studies viewpoint. This gap highlights the nascent stage of PI-DT in academic discourse, echoing the call for a more robust theoretical foundation in this domain. Vial (2019) acknowledges this need by emphasizing the transformative potential of DT across industries but points out the scarcity of research specifically within PI. The review, by proposing a future research agenda across key areas (Operations Management, Strategic Management, Organization's Theory and Stakeholder's Theory), sets a foundational base for theoretical exploration and scholarly inquiry. This approach aligns with the views of Fichman et al. (2014) who argue for the necessity of interdisciplinary research agendas to fully understand DT's impacts.

The review's inclusion of diverse digital technologies (e.g., IoT, AI, Blockchain) within PI's value chain phases (Drug Discovery, Clinical Trials, Manufacturing) represents a significant integration of technology and management theory. Such integration is crucial for developing a comprehensive understanding of how DT reshapes industry practices and management strategies. Tidd and Bessant (2020) discuss the importance of this integration for innovation management, suggesting that understanding the role of technology in organizational change is vital for strategic innovation. Similarly, Westerman et al. (2014) highlight how digital technologies are redefining competitive landscapes, necessitating a reevaluation of management theories to incorporate these technological advancements.

Identifying research gaps in literature also serves as a directive for future scholarly efforts, encouraging the development of new theoretical frameworks to address these gaps. The provided research agenda serves this aim. This approach is in line with the work of Benner and Tushman (2003) who emphasize the value of research diversity for the advancement of management studies. The systematic review calls for a deeper investigation into the comprehensive impact of DT across the entire pharmaceutical value chain, echoing the sentiments of scholars like (Yoo et al., 2010), who argue for a more nuanced understanding of digital innovation's role in organizational transformation. By outlining the future research agenda, this literature review advocates for a multidisciplinary approach to studying PI-DT. This suggestion is supported by the work of (Autio et al., 2018) who argue that the complexities of digital ecosystems can only be fully understood through a multidisciplinary lens. Such research is crucial for developing a holistic understanding of DT's implications, integrating insights from operations management, strategic management, organizational theory, and stakeholder theory to foster a comprehensive theoretical framework.

The review not only identifies the need for theoretical advancements in the context of PI-DT but also sets the stage for future research to explore these areas. This aligns with the argument presented by Nambisan et al. (2019) regarding the evolving nature of innovation in the digital age and the consequent need for management theory to adapt. By focusing on the integration of digital technologies within PI and their multifaceted impacts, the review contributes to the broader discourse on digital transformation and its theoretical implications.

Overall, the systematic literature review on DT in the pharmaceutical industry not only highlights the existing gaps in the literature but also proposes a structured agenda for future research. This endeavor not only advances theoretical understanding within the field of management studies but also encourages the integration of technological and management theories to address the complex dynamics of digital transformation in the pharmaceutical industry.

For practitioners in the pharmaceutical industry, the systematic literature review offers several actionable insights.

The review provides a comprehensive overview of the key technologies driving DT in PI and their applications across different value chain phases. This serves as a guide for pharmaceutical companies to prioritize their DT initiatives, focusing on technologies and areas with the highest potential impact on their operations and strategic goals. The outlined future research agenda and identified research gaps offer insights into emerging trends and challenges in PI-DT. Practitioners can use this information to inform their strategic planning and investment decisions, ensuring they are aligned with the future direction of technology and

Table 6
Future research agenda for the Stakeholder's Theory Research area.

Topic	Aggregated area	Related technologies	Value chain	Literature	Research questions
Environmental Footprint	Environmental	Digital Twins, AR, VR, Cloud, 3D, Big Data, AI, Blockchain	MK, SC, MA	Chen et al., 2020; Aquino et al., 2018; Ding, 2018; Nguyen et al., 2022; Shamsuzzoha et al., 2020; M. Sharma et al., 2022; Ghadge et al., 2022; Zakari et al., 2022; Hosseini Bamakan et al., 2021; Ding, 2018; M. Sharma et al., 2022; Burrichter et al., 2022; M. Sharma et al., 2023; Ertz et al., 2022; Junaid et al., 2023	• How can the concept of circular economy be integrated into the pharmaceutical value chain to promote resource efficiency, waste reduction, and the reuse or recycling of materials? • What role can AR and VR technologies play in optimizing material usage and minimizing waste generation in pharmaceutical manufacturing? • In what ways can 3D printing technology be leveraged to reduce waste, enable on-demand manufacturing, and enhance the overall environmental performance of pharmaceutical production?
Sustainability Certifications (Integration with UN's SDGs Goals)	Environmental	3D, IoT, Cloud, Blockchain, AI, Big Data	MK, SC	Saha et al., 2022; Ding, 2018; M. Sharma et al., 2022	• Does the integration of sustainability certifications into pharmaceutical companies enhance sustainability performance perception of patients? • How can blockchain technology facilitate the verification and validation of sustainability claims and certifications across multiple stakeholders in the pharmaceutical value chain?
Customization, Personalization, and Precision Medicine	Impact on Patient	IoT, Cloud, Big Data, Blockchain, AI, Robots, 3D, AR, VR, Digital Twins	MA, SC	Silva et al., 2020; Aquino et al., 2018; Ding, 2018; Denicolai and Previtali, 2020; M. Sharma et al., 2022; Kordestani et al., 2023; Liu et al., 2021a, 2021b; Ghadge et al., 2022; Arief et al., 2022	• How can 3D printing technology be leveraged to customize drug dosage forms and delivery systems to meet individual patient needs and improve medication adherence in the context of precision medicine? • What role can AR, VR and AI-powered chatbots play in supporting patient self-management, treatment monitoring, and remote consultations for personalized medicine interventions? • What are the factors influencing patient acceptance, trust, and adoption of personalized medicine technologies and interventions, and how can these barriers be addressed through effective communication strategies and patient-centric engagement approaches?
Ensuring Drug Safety, Counterfeit Drug Prevention and Higher Accessibility to Drugs	Impact on Patient	AI, IoT, Cloud, Blockchain, 3D, Big Data	MA, SC	Kulkov, 2021; Chen et al., 2020; Zakari et al., 2022; Zulfiqar et al., 2022; M. Sharma et al., 2022; Lima Jr et al., 2021; Silva et al., 2020; Aquino et al., 2018; Ding, 2018; Nguyen et al., 2022; Liu et al., 2021a, 2021b; Hosseini Bamakan et al., 2021; Kordestani et al., 2023; Ghadge et al., 2022; Ertz et al., 2022; Junaid et al., 2023	• How can AI-powered chatbots and virtual assistants enhance patient education and provide accurate information about drug usage, potential side effects, and interactions, contributing to higher drug safety awareness and patient empowerment? • How can big data analytics and predictive modeling be applied to identify patterns and trends in adverse drug events, enabling proactive measures in market access and supply chain to prevent potential harm to patients? • How the use of Blockhain can support in fighting counterfeited drug markets?
Data Transparency for Regulatory Validation	Regulatory Compliance	Blockchain, Big Data, IoT	DD, CT, MK, SC, MA	Zakari et al., 2022; Hosseini Bamakan et al., 2021; Nguyen et al., 2022; Arief et al., 2022; M. Sharma et al., 2022; Alharthi et al., 2020; M. Sharma et al., 2023; Ertz et al., 2022; Junaid et al., 2023; Zakari et al., 2022; Hosseini Bamakan et al., 2021; Nguyen et al., 2022; Arief et al., 2022; M. Sharma et al., 2022; Alharthi et al., 2020; M. Sharma et al., 2023; Ertz et al., 2022; Junaid et al., 2023	• How can blockchain technology be implemented in drug discovery to ensure transparent recording and verification of research data, facilitating regulatory validation and accelerating the development of new drugs? • What are the key considerations and requirements for establishing a secure and trusted data infrastructure based on blockchain technology to support regulatory validation processes across the value chain phases? • How can data governance frameworks be designed and implemented to ensure data integrity, privacy, and security in the context of data transparency for

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Table 6 (*continued*)

Topic	Aggregated area	Related technologies	Value chain	Literature	Research questions
					regulatory compliance, particularly when utilizing big data and IoT technologies?
Enhanced adherence to Regulatory standards	Regulatory Compliance	IoT, Blockchain, Cloud, AI, Digital Twins	MK, SC	Silva et al., 2020; Arief et al., 2022; M. Sharma et al., 2022; Ghadge et al., 2022; Zakari et al., 2022; Kulkov, 2021; Kordestani et al., 2023	• How can IoT devices and sensors be utilized in the manufacturing phase to monitor and ensure real-time compliance with regulatory standards, such as Good Manufacturing Practices (GMP) and quality control measures?
Need for standardized data sharing protocols and Updated Regulatory Framework	Regulatory Compliance	Big Data, Blockchain, AI, 3D, Cybersecutrity, Digital Twins,	DD, CT, MK, SC, MA	Nguyen et al., 2022; Zulfiqar et al., 2022; M. Sharma et al., 2022; Kordestani et al., 2023; Liu et al., 2021a, 2021b; Ghadge et al., 2022; Argiyantari et al., 2020; Kulkov, 2021; Arief et al., 2022; Wu and He, 2020; Chen et al., 2020; Kordestani et al., 2023	• What are the key considerations in developing standardized data sharing protocols that enable seamless integration and interoperability across different systems and stakeholders in the value chain phases while addressing privacy concerns and ensuring compliance with data protection regulations? • How can the replacement of manual data improve regulatory adherence and reduce environmental footprint?
Eliminating Discrimination in HR recruitments	Governance	AI	MA	Kulkov, 2021	• How can AI eliminate discriminations in the recruitment process of new employees? • What are the main barriers and benefits of deploying AI for this matter?
Patient-Data Security and Privacy	Governance	Cloud, Big Data, Blockchain	SC, MA	Silva et al., 2020; Nguyen et al., 2022; Denicolai and Previtali, 2020; Arief et al., 2022; Zulfiqar et al., 2022; Kordestani et al., 2023; Alharthi et al., 2020; Liu et al., 2021a, 2021b; Ghadge et al., 2022	• What are the ethical and privacy considerations associated with the collection, analysis, and use of patient data for improving patient retention, and how can organizations establish robust data governance frameworks and practices to ensure compliance and maintain trust, ultimately strengthening their competitive advantage?
University Education Gap	Social	IoT, Cloud, Big Data, Blockchain, AI, Robots, 3D, AR, VR, Digital Twins	MA	Kulkov, 2021; Silva et al., 2020; Liu et al., 2021a, 2021b	• What strategies and policies can be implemented to foster closer collaboration between academia and regulatory authorities, enabling universities to address the education gap and produce graduates with the necessary regulatory compliance competencies?

Abbreviations: Drug Development (DD), Clinical Trials (CT), Manufacturing (MK), Supply Chain (SC), Market Access (MA), Pharmaceutical Industry (PI), Digital Transformation (DT), Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), Internet of Things (IoT).

management practices in the industry. By highlighting the importance of integrating digital technologies into pharmaceutical management practices, the review underscores the potential for these technologies to enhance competitive advantage. Companies that effectively leverage DT can improve their operational efficiency, agility, and stakeholder engagement, positioning themselves favorably in a rapidly evolving industry landscape. The focus on Stakeholder's Theory research underscores the importance of considering the diverse interests and impacts of DT on various stakeholders, including patients, regulatory bodies, and the environment. Practitioners are encouraged to adopt a more stakeholder-centric approach to DT, which can lead to more sustainable and socially responsible business practices. The review points to the need for standardized data sharing protocols and updated regulatory frameworks to support DT in PI. Practitioners can leverage these insights to advocate for regulatory changes that facilitate innovation while ensuring patient safety and data security.

To sum up, the systematic literature review on the DT of the Pharmaceutical Industry not only advances theoretical understanding but also offers practical guidance for navigating the challenges and opportunities of digital transformation in a highly regulated and competitive sector.

7. Research limitations

It is necessary to recognize the limitations of this work. First, the restrictions due to limited source availability. Despite the utmost efforts to access relevant research studies, certain articles were inaccessible. This could potentially introduce bias and limit the inclusiveness of this review. Second, despite the attempts to include a wide range of studies, some pertinent articles may have been excluded due to selection criteria and search terms. Third, the quality and rigor of the included studies varied, which may have impacted the strength of the evidence hereby synthesized. Fourth, given the rapidly progressing nature of PI-DT, it is conceivable that some recent advancements were not captured in the Literature available until the date of this review.

8. Conclusions

In conclusion, this literature review addressed the current knowledge gap in the field of PI-DT, which has been relatively underdeveloped in Management Studies despite the increasing attention given to DT by practitioners. Indeed, while practical applications of PI-DT have been explored extensively in the practitioner's literature, Management studies was still limited by, e.g., being too practitioner-focused, neglecting recent PI-DT developments arising from the Covid-19 pandemic, and, most importantly, lacking a comprehensive research agenda in the context of Management studies to boost this subject as field of debate. By reviewing a framework of 35 relevant articles, this SLR contributed to the existing literature by presenting a well-structured research agenda for PI-DT Management studies. Researchers can explore strategies and technologies that improve *operational activities*, investigate the role of PI-DT in gaining a superior *competitive advantage*,

examine the *changes to organization's* processes associated with DT initiatives, and investigate the source PI-DT *Impacts on various Stakeholders*. These research directions offer a solid foundation for additional scholarly inquiry and contribute to the development of knowledge in the field of PI-DT management studies.

CRediT authorship contribution statement

Mario Miozza: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Investigation, Methodology. **Federica Brunetta:** Conceptualization, Supervision, Writing – original draft, Writing – review & editing. **Francesco Paolo Appio:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Data availability

No data was used for the research described in the article.

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