KMANPUB | AI and Tech in Behavioral and Social Sciences Vol. 4 No. 1 (2026): 1-14

Article history:
Received 19 September 2025
Revised 12 October 2025
Accepted 23 November 2025
Published online 01 January 2026

Designing a Meta-Synthesis Model of Smartization of the Value Chain with an Industry 4.0 approach

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A r t i c l e I n f o

Article type:
Review Article

How to cite this article:
Babaie, M., Erajpour, A., & Ehtesham Rasi, R. (2026). Designing a Meta-Synthesis Model of Smartization of the Value Chain with an Industry 4.0 approach. *AI and Tech in Behavioral and Social Sciences, 4*(1), 1-14.
https://doi.org/10.61838/kman.aitech.4483

A B S T R A C T

In the era of the Fourth Industrial Revolution, organizations are compelled to redesign their value chains with a smart and technology-oriented approach. This transformation requires the precise identification of the dimensions and components influencing the smartization of value chains. The aim of this study is to develop a meta-synthesis model that reflects the transformative perspective of smart value chain development in the context of Industry 4.0. The innovation and novelty of the present study lie in its introduction of smart value chain management within the context of the Fourth Industrial Revolution, exploring new and practical models for optimizing supply chain processes and enhancing organizational efficiency. The research is grounded in an interpretivist paradigm and employs the meta-synthesis method to identify a localized framework for value chain smartization. The statistical population consists of academic resources obtained through a systematic search of reputable databases, based on inclusion and exclusion criteria such as relevance, quality, and publication year. All credible scientific documents published between 2018 and 2025 that address the paradigms of smart value chains and the Fourth Industrial Revolution were reviewed. Initially, 153 articles were extracted from reputable databases such as ScienceDirect, Emerald, Sage, Taylor & Francis, and others. After screening titles and abstracts, 38 relevant articles (including 18 literature reviews and 20 empirical studies) were selected and analyzed from the Web of Science database. Structural summaries of these articles led to the identification of broader thematic categories. The findings highlight three key thematic areas linked to smart value chains and Industry 4.0. Through the meta-synthesis approach, eight dimensions and 35 components were extracted: Industry 4.0 technologies, process digitalization, data analytics and intelligent decision-making, value chain integration, resilience and agility, sustainability and social responsibility, organizational empowerment, and business model innovation. The results of this study can provide a strategic roadmap for managers, policymakers, and digital transformation designers across various industries and offer a solid theoretical foundation for future research.

Keywords: *Fourth Industrial Revolution, Value Chain, Meta-Synthesis Model, Smartization*

1. Introduction

In the past decade, technological advancements brought about by the Fourth Industrial Revolution have transformed the traditional boundaries of production, logistics, and service delivery. This revolution, powered by technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Blockchain, Cyber-Physical Systems, and Big Data, has led to the emergence of a novel concept known as the "Smart Value Chain" (Manurung et al., 2024). The smart value chain is not merely a digital structure for the exchange of goods and information; it is a dynamic and self-learning system capable of real-time decision-making, enhancing productivity, and generating sustainable value across organizational and inter-organizational processes. In this context, industries and organizations must redesign their operational models based on the approaches of the Fourth Industrial Revolution to remain competitive and respond to unstable environments (Apel et al., 2024).

The shift from manual production systems to large-scale mechanization initially began in Britain in the late 18th century. This era, which featured significant technological changes and a series of innovations, is referred to as the Industrial Revolution. The advent of mechanization not only led to increased productivity, economic rewards, and improved living standards for the British people but also sparked further intellectual and technical creativity. Following the success of the first revolution, this process triggered a series of subsequent industrial revolutions, spreading to other parts of the world and becoming a global phenomenon. The Second Industrial Revolution occurred in the late 19th century, marked by the emergence of electricity to enable mass production. It was followed by the Third Industrial Revolution in the late 20th century, characterized by the use of information technology and electronics to automate production (Hakola et al., 2025; Liu et al., 2024).

Research gaps in the field of smart value chain development often relate to a lack of clarity in understanding, applying, and integrating the value chain at the strategic level of organizations. These gaps arise from the dynamic and complex nature of knowledge, operational challenges, and rapid changes in the business environment. Some of the most critical of these gaps are as follows:

- Insufficient research on the impact of emerging technologies such as AI, Blockchain, and Big Data on smart value chain development (Su et al., 2025).
- Lack of clarity on how to use digital tools to accelerate smart value chain processes.
- A shortage of comprehensive models explaining the relationship between smart value chain development and financial performance, innovation, and competitiveness (Thao et al., 2024).
- The need to develop measurable indicators to assess the impact of smart value chains at various organizational levels.
- The influence of organizational culture and individual behavior on the success of smart value chain initiatives.
- Examination of psychological, social, and cultural barriers to smart value chain development, particularly in multinational organizations.
- The implementation of smart value chains in dynamic and uncertain environments (Utomo et al., 2025; Xu et al., 2024).

The progress of Industry 4.0 and the emergence of new technologies such as IoT, AI, Big Data, and 3D printing require organizations to be managed in new ways to fully leverage the benefits of these technologies (Liu & Lv, 2025). In the Fourth Industrial Revolution, many processes and tasks are carried out by intelligent and automated systems, which may result in the loss of traditional human knowledge. Therefore, presenting a meta-synthesis model for smart value chain development can help organizations preserve and effectively transfer their critical knowledge, even in times of workforce reduction or major structural changes (Bubakar et al., 2019).

Despite significant progress, the research literature on smart value chains remains fragmented, diverse, and lacking a comprehensive and integrated framework. Different studies have each focused on various aspects of this transformation—some on digital technologies, others on management issues, and yet others on sustainability and supply chain resilience. This fragmentation has made it difficult to develop a holistic understanding of the dimensions and key components of the smart value chain, leaving decision-makers and researchers uncertain about how to implement this concept effectively (Liu & Lv, 2025). Therefore, there is a growing need for an integrative study aimed at identifying, categorizing, and explaining the core components of this field.

The meta-synthesis method, with its ability to integrate and qualitatively analyze findings from previous studies, is a suitable approach to address this scientific gap. Utilizing this method, the present research aims to identify the dimensions and components of value chain smartification,

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E-ISSN: 3041-9433

with a focus on the requirements and capabilities of the Fourth Industrial Revolution, and to propose a conceptual model. The main research question is:What is the meta-synthesis model of value chain smartification in the era of the Fourth Industrial Revolution?

This research utilizes advanced technologies such as IoT, AI, blockchain, and big data analytics to improve decision-making speed and accuracy, enhance digital communication across different sectors, and strengthen resilience to disruptions. Furthermore, by focusing on innovative concepts, the study facilitates the design of digital business models that allow organizations to respond more effectively to the evolving market needs, ultimately generating new value and competitive advantages.

This study seeks to present a meta-synthesis model of an indigenous value chain smartification framework for the era of the Fourth Industrial Revolution.

2. Theoretical Foundations and Literature Review

2.1. Smartification of the Value Chain

In the digital age, with the advent of advanced technologies associated with the Fourth Industrial Revolution, the concept of "value chain smartification" has emerged as a novel approach in operations management and organizational value creation (Tseng et al., 2025). This concept involves leveraging emerging technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning, Big Data, Blockchain, and Cyber-Physical Systems to optimize, automate, and enhance the agility of the value chain across all stages from raw material sourcing to final customer delivery. The primary objective of smartification is to enhance productivity, flexibility, and responsiveness of value chains to the complex, dynamic, and uncertain conditions of today's markets (Anshari et al., 2022).

According to Liu et al. (2021), value chain smartification entails the integration of process digitalization with intelligent analytical and decision-making capabilities (Liu et al., 2024). This results in transparency, real-time responsiveness, and seamless interactions among internal components and external partners of the value chain. Such a transformation requires advanced technological infrastructure, integrated information systems, and agile, data-driven management approaches (Alhawamdeh & Lee, 2024).

Bai et al. (2022) further emphasize that smartification is not merely a technological shift but also an organizational and systemic transformation — encompassing a culture of innovation, organizational learning, and business model redesign (Bai et al., 2020).

From the perspective of Sharma & Joshi (2023), the three main features of a smart value chain are:

1. Automation of processes through decision-making algorithms,
2. Predictive capabilities using big data analytics, and
3. Operational flexibility supported by integrated digital infrastructures.

They argue that in such value chains, data is regarded as the primary source of value creation. Intelligent systems can process and analyze real-time environmental and organizational data to make precise, rapid, and targeted decisions (Barbosa & Saisse, 2019).

In this context, Wamba et al. (2020) and Bag et al. (2021) suggest that value chain smartification not only improves organizations' operational performance but also serves as a tool for enhancing sustainability, resilience, and global competitiveness. They believe that adopting a smart approach to value chain design and management significantly enhances an organization's ability to anticipate disruptions, respond to crises, reduce costs, and increase customer satisfaction.
Overall, value chain smartification establishes a strategic linkage between technology and management, making it one of the most transformative changes in supply chain management in recent decades (Barbosa et al., 2020).

2.2. Smartification of the Value Chain in the Fourth Industrial Revolution

The study by Liu et al. (2021) indicates that in the Fourth Industrial Revolution, smartification of the value chain is not merely about digitizing processes (Liu et al., 2024). The primary focus is on enhancing predictive capabilities, learning, and autonomous decision-making across supply and production chains. They emphasize that intelligent interconnection among machines, humans, and systems through real-time data can enable resource optimization, waste reduction, and efficiency enhancement. From this perspective, the value chain becomes an integrated and intelligent system with memory, logic, and autonomous responsiveness (Birasnav & Bienstock, 2019).

Bag et al. (2021) and Wamba et al. (2020) argue that smartifying the value chain under the Industry 4.0 paradigm is not merely a technological transformation; it also involves a shift in management logic, organizational culture, and

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AI and Tech in Behavioral and Social Sciences
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business models. They assert that organizations need to revise traditional structures, establish data-driven ecosystems, and empower employees to interact with emerging technologies. This systemic transformation enables organizations to become not only responsive but also proactive, flexible, and resilient in the face of crises (Bruno et al., 2020).

In the study by Sharma & Joshi (2023), it is emphasized that organizations that have redesigned their value chains using smart technologies have achieved sustainable competitive advantage, improved customer experience, reduced response times, and moved toward sustainable development. According to them, smartification serves as a critical tool in addressing global disruptions (such as the COVID-19 crisis or supply chain fluctuations) and drives organizations toward models based on advanced analytics, real-time decision-making, and environmental sustainability. Overall, smartification of the value chain in the Fourth Industrial Revolution is recognized as a driving force for organizational transformation in the future world (Buer et al., 2018).

In the digital era—characterized by rapid changes, intense market volatility, and increasing complexity of global supply chains—value chain smartification is considered a vital solution for enhancing organizational resilience. Technologies such as machine learning, the Internet of Things (IoT), and big data empower organizations to analyze real-time data, predict trends, make intelligent decisions, and prevent disruptions in critical processes. In this context, Barbosa-Póvoa et al. (2020) stress that smartification enhances the adaptive capacity of value chains to unpredictable conditions (Buřita et al., 2018).

From an economic perspective, smartification of the value chain can significantly reduce operational costs, minimize waste, and improve productivity. Through the use of technologies such as advanced automation and digital integration, repetitive processes are eliminated, and human errors are reduced. In their research, Dalenogare et al. (2020) showed that companies that fully adopted digitalization in their value chains managed to save up to 30% in operational costs (Dalenogare et al., 2018). This not only boosts profitability but also enhances an organization's competitiveness on the international stage (Castro et al., 2021).

In addition to economic benefits, smartification plays a pivotal role in achieving sustainable development goals. Efficient energy use, transparent resource tracking, pollutant reduction, and improved environmental productivity are among the notable outcomes of this transformation. According to Raj et al. (2022), Fourth Industrial Revolution technologies enable real-time environmental and social monitoring, guiding organizations toward greater social responsibility. Thus, smartification of the value chain is not only a competitive tool but also a platform for organizations to fulfill their responsibilities toward society and the environment (Chaka, 2020).

2.3. *Literature Review*

Table 1 summarizes the most important studies conducted on value chain smartification and the Fourth Industrial Revolution.

Table 1

Research Background on Value Chain Smartization and Industry 4.0

No.	Source (Year)	Research Title	Key Findings and Results
1	(Chaka, 2020)	Smart Labels as Enablers of Product Digital Passports in Circular Electronic Value Chains	This study investigates the role of smart labels in implementing product digital passports within circular value chains in the electronics industry. Findings show that smart labels provide real-time, traceable, and accurate data regarding origin, materials, usage, and recycling, enhancing lifecycle management and transparency. The technology supports sustainability goals and fosters collaboration among stakeholders.
2	(Xu et al., 2024)	Behavioral Performance of Marketing Relationships in Credit-Based Value Chain Initiatives	This study explores the behavioral performance of marketing relationships in credit-based value chain initiatives. It shows that trust, commitment, and cooperation among value chain actors are crucial for the success of credit schemes aimed at empowering small producers. Strong marketing relationships enhance financial access, reduce credit risk, and improve economic efficiency.
3	(Liu & Lv, 2025)	Digital Transformation of Industry 4.0 and Opportunities for Supply Chain Resilience: A Comprehensive Review and Strategic Roadmap	This systematic review analyzes the impact of Industry 4.0 technologies on supply chain resilience. It reveals that integrating IoT, AI, blockchain, and cloud computing significantly enhances prediction, response, and recovery capabilities. The study proposes a strategic roadmap for managers to guide digital transformation toward flexibility and sustainability.

AITBSS
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4	(Tseng et al., 2025)	Sustainable Industrial Digital Transformation Based on Smart Blockchain Technology	This research examines the role of smart blockchain in achieving sustainable industrial digital transformation. Findings show that blockchain ensures transparency, security, and traceability, enabling efficient and environmentally friendly digital transformation. Smart contracts in supply chains reduce costs, boost stakeholder trust, and improve environmental performance.
5	(Anshari et al., 2022)	Causality in Sustainable Supply Chain Management Practices in Indonesia's Coffee Industry Using Qualitative Data: Digital Integration Leads to Performance Improvement	Using qualitative data, this study explores causal links between sustainable supply chain practices and performance in Indonesia's coffee industry. Digital integration (e.g., data systems and analytics tools) improves decision-making, quality, waste reduction, and both financial and environmental performance.
6	(Bai et al., 2020)	A Systematic Review and Meta-Synthesis of Barriers in Off-Site Construction Projects	This study identifies barriers in off-site construction projects using a systematic review and meta-synthesis. Challenges include lack of standardization, supply chain coordination issues, cultural resistance, and insufficient technological infrastructure. Findings guide project designers and policymakers in enhancing productivity and quality.
7	(Alhawamdeh & Lee, 2024)	Industry 4.0 at the Intersection of Knowledge Management and Digital Humanities	This article explores the intersection of knowledge management and digital humanities in the context of Industry 4.0. It shows that emerging technologies such as AI, machine learning, and natural language processing expand knowledge management capabilities and redefine the role of humanities in the digital era. Emphasizes interdisciplinary convergence for innovative, human-centric policy design.
8	(Barbosa & Saisse, 2019)	Assessing Industry 4.0 Technologies from a Sustainability Perspective	This paper evaluates Industry 4.0 technologies (e.g., IoT, 3D printing, big data analytics) in terms of sustainability. The findings suggest these technologies can simultaneously improve production efficiency, resource optimization, and environmental impact. It offers a framework to help decision-makers balance economic growth with environmental sustainability.
9	(Barbosa et al., 2020)	Hybrid Project Management for Socio-Technical Digital Transformation Platforms	This study presents hybrid project management as a solution for managing complex digital projects with technical and social dimensions. Combining traditional and agile methods increases flexibility, stakeholder engagement, and success in implementing digital

2.4. Innovation and Research Gap

According to Table 2, the innovation of the present study lies in the simultaneous utilization of two paradigms—smart value chain and the Fourth Industrial Revolution—and the development of a new integrated model for intelligent value chains. From a methodological perspective, this research employs a comprehensive meta-synthesis approach to identify dimensions and components and construct a conceptual model. Additionally, the research offers a localized and context-specific perspective on the smart value chain in the era of Industry 4.0, making it a novel contribution to the literature.

Table 2

Research Gap and Innovation Compared to Previous Studies

No.	Source	Quantitative	Qualitative	Meta-analysis	Meta-synthesis	Value Chain	Industry 4.0	Smart Value Chain in Industry 4.0
1	(Manurung et al., 2024)	–	✓	–	✓	–	✓	–
2	(Apel et al., 2024)	–	✓	–	–	–	–	✓
3	(Hakola et al., 2025)	✓	✓	✓	–	–	–	✓
4	(Liu et al., 2024)	–	✓	–	–	✓	✓	–
5	(Su et al., 2025)	✓	–	–	–	–	–	✓
6	(Thao et al., 2024)	✓	–	–	–	–	✓	–
7	(Utomo et al., 2025)	–	✓	–	✓	–	–	✓
8	(Xu et al., 2024)	–	✓	–	–	–	✓	–
9	(Bubakar et al., 2019)	✓	–	–	–	✓	–	✓
10	(Ghobakhloo et al., 2025)	✓	–	–	–	✓	–	✓
11	(Liu & Lv, 2025)	✓	–	–	–	–	–	–
12	(Tseng et al., 2025)	✓	–	–	–	–	✓	–
13	(Anshari et al., 2022)	✓	–	–	–	–	–	✓
14	(Alhawamdeh & Lee, 2024)	✓	–	–	–	–	✓	–
15	(Bai et al., 2020)	✓	–	–	–	✓	–	✓

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E-ISSN: 3041-9433

16	(Barbosa & Saisse, 2019)	✓	–	–	–	–	–	✓
17	(Barbosa et al., 2020)	✓	–	–	–	–	✓	–
18	(Birasnav & Bienstock, 2019)	✓	–	–	–	✓	–	–
19	(Bruno et al., 2020)	✓	–	–	–	✓	–	–
20	(Buer et al., 2018)	✓	–	–	–	–	–	✓
21	Present Study	–	✓	–	✓	✓	✓	✓

3. Methods and Materials

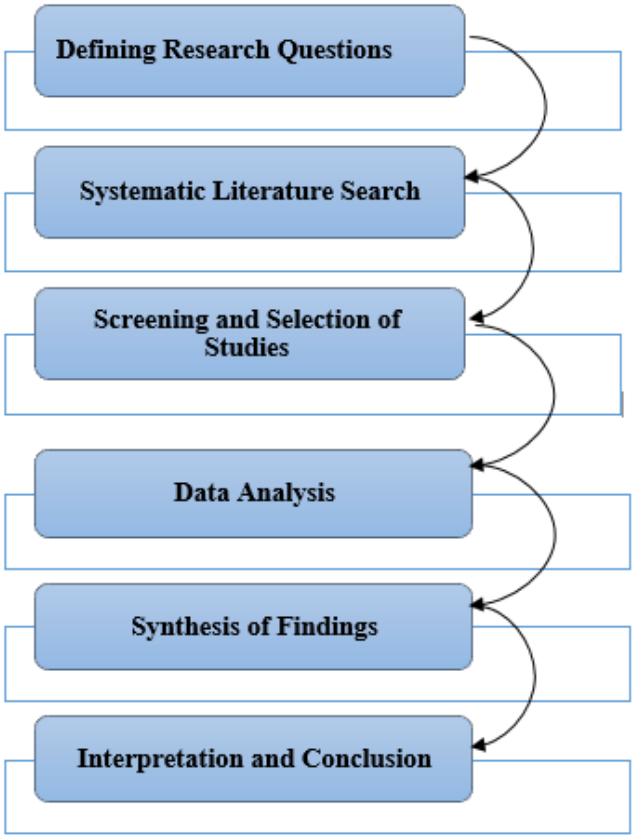
The present study is grounded in the interpretive paradigm and employs the meta-synthesis method (qualitative meta-study) to identify a localized pattern for smart value chain development in the context of the Fourth Industrial Revolution. Meta-synthesis is a qualitative research approach used to integrate and interpret findings from previous qualitative studies, with the aim of extracting new insights, conceptual frameworks, or theories. It involves a systematic review of existing literature, enabling a deep, critical analysis of studies and facilitating the synthesis of current knowledge to propose novel perspectives.

This research follows a descriptive–qualitative design. Unlike meta-analysis, which focuses on aggregating quantitative data, meta-synthesis is centered on analyzing qualitative studies to reach a more comprehensive, in-depth, and holistic understanding of the phenomenon under investigation.

Figure 1 presents the main stages of the meta-synthesis methodology used in this study. These stages include:

Figure 1

Stages of Meta-Synthesis (Bai et al., 2020)



Defining the research question

1. Systematic search of related studies
2. Determining inclusion and exclusion criteria for article selection (e.g., relevance, quality, publication year)

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E-ISSN: 3041-9433

3. Critical review and synthesis of selected sources

The statistical population of the study includes scientific sources published between 2018 and 2025 from reputable international databases such as Scopus, PubMed, and Web of Science, focusing on the topics of value chain smartization and the Fourth Industrial Revolution.

The search strategy was based on a set of keywords related to smart value chains and Industry 4.0. These keywords are presented in Table 3, and they were used to retrieve relevant studies from the Web of Science database.

Table 3

Search Keywords Used in Scientific Databases (Source: Research Findings)

Keywords Searched
Smart Value Chain
Fourth Industrial Revolution
Digital Supply Chain
Smart Manufacturing
Data Mining in Value Chain
Machine Learning
Intelligent Decision-Making
Meta-Synthesis
Fourth Industrial Revolution
Technology
Smartization / Digital Smartening
Intelligent Digitalization
Intelligent Digitalization
Artificial Intelligence (AI)
Advanced Automation

3.1. Screening and Study Selection

The initial phase involved the preliminary screening of retrieved articles to eliminate irrelevant studies. To ensure methodological rigor, quality appraisal checklists were applied to assess the reliability and validity of the selected studies.

The inclusion criteria for selecting the articles were as follows:

- Studies must be qualitative in nature.
- Publications must appear in peer-reviewed international academic journals.
- Articles must be published in English, between 2018 and 2025.
- The focus of the studies must be on value chain smartization and the Fourth Industrial Revolution.
- The findings must demonstrate high-quality content, including a clear research objective, appropriate methodology, valid data collection, and findings aligned with the research purpose.

The number of articles retrieved from each scientific database based on these criteria is presented in Table 4.

Table 4

Number of Retrieved Articles by Database (Source: Research Findings)

Database	Articles Found	Database	Articles Found
Sage	15	Google Scholar	52
Taylor & Francis	8	Emerald	18
PubMed	7	ScienceDirect	20
Springer	10	ResearchGate	23

A total of 153 articles were initially identified through keyword searches across the selected databases. Following title-based relevance screening, 53 articles were excluded. Then, a further 25 articles were removed after abstract-level screening. The remaining 75 articles underwent full-text

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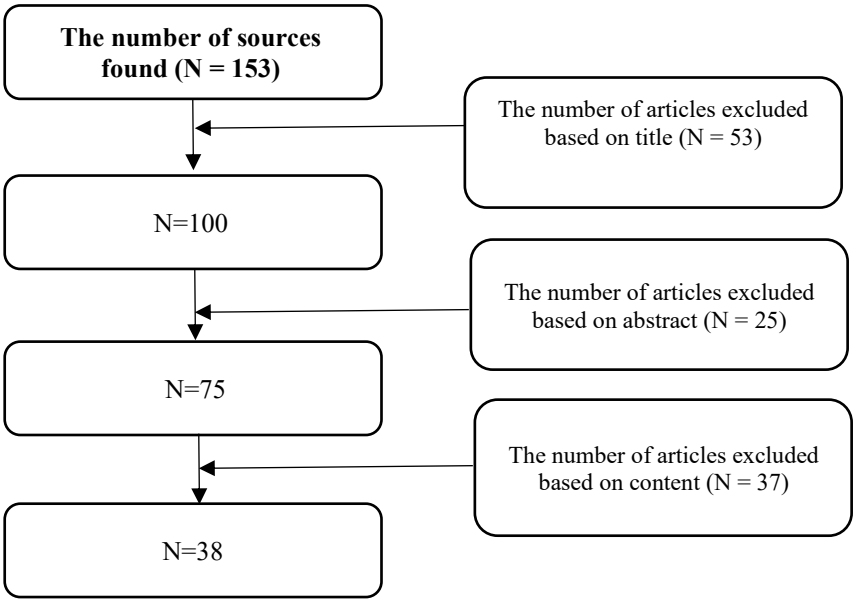
content analysis, and finally, 38 articles were selected for in-depth coding and qualitative synthesis (see Figure 2).

Figure 2

Searching and Selecting Relevant Articles (Source: Research Findings)



3.2. *Data Extraction (Article Analysis)*

To extract the relevant data, a meta-synthesis extraction sheet adapted from Khenifer and Moslemi (2022) was used. This template includes four main sections: Title, Text, Concepts (components), and Source.

3.3. *Qualitative Data Analysis and Synthesis*

The findings were analyzed and synthesized using a three-stage thematic coding process, a technique commonly used in thematic content analysis:

- **Stage 1 (Open Coding)**: Initial concepts and codes were identified by five expert reviewers.
- **Stage 2 (Axial Coding)**: Relationships between identified concepts were explored and categorized.
- **Stage 3 (Selective Coding)**: Final themes were synthesized by integrating, refining, and validating the main categories.

The result was the development of higher-order themes and dimensions forming the basis of the conceptual framework.

3.4. *Quality Control (Interpretation and Conclusion)*

The final results were interpreted and presented in response to the research question. Limitations of the study were discussed, and suggestions for future research were provided.

3.5. *Reporting*

The final report was compiled in a clear, systematic, and academically rigorous format, ensuring transparency and reliability of the research process and findings.

4. Findings and Results

After screening the research data and selecting from 153 articles, a total of 38 relevant articles evaluated using various research methodologies (from over 30 academic journals) were chosen. We have 7 Steps of meta-synthesis as below:

Step 1: Defining the Research Question

In this initial step, the main objective of the study was clearly defined, and the core research question was formulated. The question needed to be specific, focused, and suitable for qualitative analysis.

The main research question was defined as:

"What is the appropriate model for smart value chain development under the context of Industry 4.0, considering local conditions?"

Key concepts such as "smartization," "value chain," and "Industry 4.0" were identified.

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E-ISSN: 3041-9433

The goal was to explore dimensions, components, and their interrelationships from prior qualitative studies.

Step 2: Systematic Literature Search

Relevant academic literature was searched systematically across multiple databases to identify studies related to the research topic.

Databases such as Scopus, Web of Science, ScienceDirect, Springer, Emerald, and Google Scholar were used.

Keywords included:

"Industry 4.0", "Smart Value Chain", "Digital Transformation", "Supply Chain 4.0", "Smart Manufacturing"

Inclusion criteria:

Peer-reviewed research articles

Focus on Industry 4.0 and smart supply/value chains

Published between 2013 and 2023

This search yielded 153 initial articles.

Step 3: Screening and Selection of Final Studies

The identified articles were evaluated based on their relevance to the research objectives and their methodological rigor. Article titles, abstracts, methodologies, and findings were reviewed.

Exclusion criteria:

- Duplicate studies
- Irrelevant to smart value chain or Industry 4.0 context
- Lack of a clear research methodology

As a result, 38 final articles were selected for in-depth analysis.

These articles featured various methodologies, including case studies, literature reviews, surveys, simulations, and qualitative analysis (Table 5).

Step 4: Extraction of Initial Concepts (Open Coding)

Key qualitative data and concepts were extracted from the selected studies and labeled as open codes.

Each paragraph or significant section of the articles was analyzed, and recurring themes, patterns, and keywords were coded.

Examples:

“Use of sensors in production” → Code: Object Connectivity

“Data analysis for accurate decision-making” → Code: Smart Prediction

Approximately 90 initial codes were identified.

Step 5: Development of Descriptive Codes

Each open code was accompanied by a descriptive code, providing clarity on its meaning and application.

Descriptive explanations were recorded in a spreadsheet alongside their corresponding open codes.

Examples:

Open code: Blockchain Transparency

Descriptive code: Enhancing trust and data transparency across partners in the value chain

These descriptive codes helped contextualize how each concept contributed to smart value chain development.

Step 6: Categorization into Themes

Codes were grouped hierarchically into Basic Themes, Organizing Themes, and Overarching Themes.

Related codes were clustered together to form basic themes.

Similar basic themes were grouped to create organizing themes.

Finally, overarching themes were developed to reflect the broader dimensions of the smart value chain.

Example (based on Table 6):

Overarching Theme: Digital Transformation

Organizing Theme: Emerging Industry 4.0 Technologies

Basic Themes: IoT, AI, Blockchain

Step 7: Final Synthesis and Conceptual Model Development

The organizing and overarching themes were synthesized into a conceptual model representing the structure and components of smart value chain development under Industry 4.0.

Based on the thematic structure, eight key dimensions of the final model were formulated, each with specific technological, managerial, and strategic components (as shown in Table 7):

- Industry 4.0 Technologies
- Process Digitalization
- Data Analytics and Intelligent Decision-Making
- Value Chain Integration
- Resilience and Flexibility in the Value Chain
- Sustainability and Social Responsibility
- Organizational Enablers
- Business Model Innovation

This final model serves as a strategic framework to guide digital transformation efforts and smart value chain development within organizations in the Industry 4.0 era.

Table 5 reports the different research approaches used in these articles along with the number of studies applying each method.

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Table 5

Research Methods Used in Selected Articles (Source: Research Findings)

Methodology	Number of Articles
Literature Review	12
Structured Questionnaires and Multivariate Analysis	8
Semi-structured Questionnaires and Qualitative Analysis	5
Simulations and Experiments	3
Case Studies	10

To perform coding using the meta-synthesis approach, themes were first extracted from the literature and then coded and categorized into a table. Table 6 presents overarching themes, organizing themes, basic themes, open codes, and descriptive codes.

Table 6

Sample Coding Table for Research on Smart Value Chain under Industry 4.0 Approach

Overarching Themes	Organizing Themes	Basic Themes	Open Codes	Descriptive Codes
Digital Transformation in Value Chain	Emerging Industry 4.0 Technologies	Internet of Things (IoT)	Object connectivity, real-time monitoring	Use of sensors for process monitoring in the supply chain
		Artificial Intelligence & Machine Learning	Data analysis, smart prediction	Enhanced decision-making through automated data analysis
		Blockchain & Data Transparency	Product tracking, data security	Increased transparency and trust in the supply chain
Resilience & Sustainability	Resilience to Disruptions	Rapid response, process recovery	Flexibility capability	Ability to quickly recover from crises
-	Environmental & Economic Sustainability	Waste reduction, resource efficiency	Resource management, pollution control	Optimal use of energy and materials in production
Digital Innovation & Value Creation	Data-Driven Decision Intelligence	Big Data analytics, data-based decisions	Management dashboards, performance metrics	Data utilization to guide strategic decisions
-	Digital Business Model Design	Platform-based, service-oriented models	Transition to platform-based models	Creating new value through digital innovation
Coordination & Collaboration	Systems and Process Integration	Digital supply chain, inter-organizational cooperation	System connectivity, data sharing	Coordination of stakeholders via shared platforms
	Digital Human Resource Empowerment	Digital skills, tech training	Employee training, knowledge development	Preparing HR for Industry 4.0

Table 7 illustrates the innovative model of smart value chain development under the Industry 4.0 framework based on the meta-synthesis method.

Table 7

Dimensions and Components of Smart Value Chain Development under Industry 4.0 Approach

No.	Dimension	Components
1	Industry 4.0 Technologies	IoT, Cyber-Physical Systems (CPS), Blockchain, Augmented & Virtual Reality, AI, Digital Twin
2	Process Digitalization	Activity automation, data integration, smart logistics, real-time control
3	Data Analytics & Intelligent Decision-Making	Data mining, Big Data, Machine Learning, Predictive Algorithms, Smart Dashboards
4	Value Chain Integration	Vertical integration (intra-organizational), horizontal integration (with partners), network collaboration, transparent tracking
5	Value Chain Resilience & Flexibility	Scenario planning, disruption management, real-time adaptability, responsive supply chain
6	Sustainability & Social Responsibility	Resource consumption reduction, renewable energy use, green life cycle, sustainable value chain
7	Organizational Enablers	Digital culture, technological leadership, employee training, organizational agility
8	Innovation in Business Models	Service-oriented models, product personalization, data-driven value creation, platforms

1. **Industry 4.0 Technologies:** Industry 4.0 technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), 3D Printing, Smart Robotics, Cloud Computing, and Blockchain provide the technical infrastructure for digital transformation within the value chain. These

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E-ISSN: 3041-9433

technologies enable real-time data collection and processing, machine-to-machine communication, process automation, and increased transparency throughout the supply chain. Their application leads to enhanced efficiency, cost reduction, and improved quality of products and services.

2. **Process Digitalization:** Process digitalization refers to the transformation of traditional physical or manual processes into digital ones through the application of modern technologies. This includes automation of operations, implementation of digital management systems, and information connectivity across different segments of the value chain. Digitalization reduces human error, accelerates operational speed, and facilitates continuous monitoring and optimization of organizational performance.
3. **Data Analytics and Intelligent Decision-Making:** As data volumes grow within organizations, leveraging big data analytics and AI algorithms to extract patterns and predict trends becomes a strategic advantage. These capabilities allow decision-makers to respond more quickly and accurately, identify risks, and adopt data-driven strategies. Intelligent decision-making enhances organizational agility and supports better anticipation of market demands.
4. **Value Chain Integration:** Integration refers to the coordination and connectivity among various internal departments and external partners within the value chain. This is achieved through shared information systems, digital platforms, and standardized data protocols. Integration enhances collaboration between suppliers, manufacturers, distributors, and customers, enabling real-time updates and agile responses to market dynamics or customer needs.
5. **Value Chain Resilience and Flexibility:** Resilience in the value chain denotes the system's capacity to withstand and recover from disruptions such as economic crises, natural disasters, or pandemics. Leveraging Industry 4.0 technologies enables organizations to maintain operations during crises and rapidly return to stable conditions. Flexibility involves the ability to adapt production, procurement, or distribution routes based on environmental changes—a capability that is strengthened by data-driven systems and automation.
6. **Sustainability and Social Responsibility:** Smart value chain development should align with sustainable development principles. This includes reducing resource consumption, optimizing energy use, minimizing pollutants, managing waste and recycling, and adhering to ethical practices in the supply chain. Social responsibility refers to the organization's commitment to fair treatment of employees, customers, communities, and the environment. Digital technologies play a crucial role in tracking, ensuring transparency, and monitoring the sustainability performance of the value chain.
7. **Organizational Enablers:** Organizational enablers such as an innovative culture, a skilled human workforce, agile structures, and digital leadership provide the necessary conditions for successful smart transformation. Without human resource preparedness, specialized training, and top management support, Industry 4.0 technologies alone cannot produce sustainable impact. Organizations that embrace adaptability, continuous learning, and strategic alignment with technological advancements are more likely to succeed in competitive environments.
8. **Business Model Innovation:** The Fourth Industrial Revolution has led to the emergence of new data-driven, platform-based, digitally enabled, and personalized business models. By harnessing advanced technologies, organizations can shift from traditional product-oriented models to service-based and value-centric approaches. These innovations include subscription-based models, mass customization, reverse logistics, and circular economy models—offering new revenue opportunities and sustainable competitive advantage.

5. Conclusion and Recommendations

In the present study, using the meta-synthesis approach, a systematic analysis of findings from 38 selected articles published between 2018 and 2025 was conducted to identify and define the key dimensions and components for designing a smart value chain model with a Fourth Industrial Revolution (Industry 4.0) approach.

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E-ISSN: 3041-9433

The findings indicate that eight main dimensions—Industry 4.0 technologies, process digitalization, data analytics and smart decision-making, value chain integration, resilience and flexibility, sustainability and social responsibility, organizational enablers, and business model innovation—are recognized as the fundamental pillars of this model. These dimensions, identified through the integration of modern theories and empirical evidence, represent a fundamental transformation in organizational value chains driven by Industry 4.0 technologies.

The analysis reveals that smart value chains not only lead to increased productivity, agility, and competitiveness, but also pave the way for achieving sustainable development goals, better market responsiveness, and enhanced innovation. Accordingly, the proposed model can serve as both a theoretical and practical framework for policymakers, managers, and researchers to plan and implement effective measures toward value chain digitalization and smart transformation.

Compared to other existing studies, this research—conducted using a meta-synthesis methodology—has unique characteristics and strengths that distinguish it. These are outlined below:

- Study (Chaka, 2020) focuses on a specific technology, namely smart tags, in the electronics industry, showing how this tool can enhance transparency and traceability in the circular value chain. In contrast, the present study offers a comprehensive and multidimensional model of smart value chain development, covering not only digital technologies like IoT and smart tags but also cultural, organizational, and strategic dimensions. The main distinction lies in its broad, systems-oriented perspective toward value chain transformations.
- The research in question focuses on the behavioral and social aspects of marketing relationships in value chain financing. While the "organizational enablers" dimension in this study includes components such as collaboration, trust, and institutional structures, study (Xu et al., 2024) is limited to only one aspect of the value chain. The strength of this study lies in its holistic and multi-faceted analysis covering technology, structure, culture, and sustainability.
- Study (Liu & Lv, 2025) provides a comprehensive review of Industry 4.0 technologies and their role in supply chain resilience, with a specific emphasis on roadmaps and practical implementation. While this study also identifies the "resilience and flexibility" dimension, its distinctive feature lies in identifying eight integrated dimensions and synthesizing findings from various scientific and practical perspectives—unlike study (Liu & Lv, 2025), which is focused on a single outcome.
- Study (Tseng et al., 2025) is centered on blockchain technology and its role in enabling sustainable digital transformation. Although blockchain is also incorporated under the "Industry 4.0 technologies" dimension in the present research, the main advantage of this study lies in its cross-disciplinary and integrative approach. Rather than concentrating on a single technology, it systematically examines the value chain within the context of the Fourth Industrial Revolution.

5.1. Practical and Managerial Recommendations

Based on the research findings, important managerial implications can be drawn for organizations aiming to develop a smart value chain within the Industry 4.0 context. First, managers need to adopt a strategic approach toward digital transformation and foster cross-functional collaboration among IT, production, supply chain, and human resources departments to develop a comprehensive roadmap for implementing emerging technologies such as the Internet of Things, artificial intelligence, blockchain, and big data analytics. This requires redesigning processes, training employees, and establishing data-driven infrastructures to enable intelligent decision-making. Moreover, focusing on innovative, platform-based business models can create new value and enhance the organization's competitive advantage.

From a policy perspective, these findings highlight the necessity of revising national industrial, educational, and infrastructural policies. Governments and policymakers should create enabling environments to expand Industry 4.0 technologies, support digital innovation, enhance digital skills in the workforce, and develop robust communication and data infrastructure. Additionally, industrial and environmental policies must emphasize the role of technology in achieving sustainability, supply chain resilience, and transparency in resource tracking. Such measures will facilitate a smooth and intelligent transition of industries and businesses into the digital era.

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E-ISSN: 3041-9433

5.2. *Recommendations for Future Researchers*

- Researchers are encouraged to validate the proposed conceptual model using quantitative methods such as factor analysis, structural equation modeling (SEM), or path analysis.
- To enhance practical relevance, future studies could apply the model through case studies in specific industries such as banking, petrochemicals, automotive, or food.
- Given the contextual nature of technology in value chains, it is recommended to conduct studies in developing countries or within small and medium-sized enterprises (SMEs) to reflect local conditions.
- Employing System Dynamics modeling tools can help simulate the interrelationships among components and analyze different smart transformation scenarios.
- Future research could develop assessment frameworks for evaluating the maturity or performance of smart value chains based on key indicators such as flexibility, sustainability, and productivity.
- To enhance the validity of identified themes, future studies should consider combining meta-synthesis with the fuzzy Delphi or classical Delphi method to incorporate expert validation.

Considering the importance of technology adoption at the human and cultural level, it is recommended that future studies explore cultural factors, organizational resistance, and leadership styles in the smart transformation journey.

Authors' Contributions

All authors equally contributed to this study.

Declaration

To correct and improve the academic writing in our paper, we used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

Declaration of Interest

The authors report no conflict of interest.

Funding

The authors declare that no financial support was received for the research, authorship, and/or publication of this article.

Ethics Considerations

This study is based solely on secondary data from published literature and did not involve human or animal subjects; therefore, ethical approval was not required.

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