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(Research Paper)

A Supply Chain Management Strategy Model to Evaluate Capabilities and Limitations of the Petrochemical Industry with the in 4.0 Approach

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Abstract

The present research aims to provide a supply chain management strategy model to evaluate the capabilities and limitations of the petrochemical industry with the In4 approach. The current research is an applied study in terms of purpose and qualitative in terms of its data type. This study identified the capabilities and limitations of using the thematic analysis method through interviews with ten industry experts. The supply chain management strategy was identified to evaluate the capabilities, including supply chain flexibility, supply chain sustainability, supply chain innovation, supply chain transparency, and supply chain coordination, which are defined by 15 indicators. At the

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same time, supply chain strategies to evaluate limitations included technological, financial, time, human resource, and organisational limitations, also outlined by 15 indicators. The findings emphasise the critical interaction between capabilities and limitations and indicate that strategically aligning these factors can result in more flexible and efficient supply chains. By strengthening capabilities while recognising, controlling, and reducing limitations, the petrochemical industries can effectively equip themselves to navigate the complexities of the industry. The findings of this research contribute to the theoretical understanding of supply chain management in the petrochemical industry sector. It likewise facilitates informed decision-making and strategic planning, ultimately contributing to sustainable growth and competitive advantage in the petrochemical industry.

Keywords: Strategy, Supply Chain, Capabilities, Limitations, Petrochemical Industry

1. Introduction

Supply chains in manufacturing during the 21st century have become increasingly complex. The intervention of the Fourth Industrial Revolution (IN4) allows for the smooth automation of manufacturing processes through the Internet of Things (IoT) and cyber-physical systems (CPS) (Ajayi & Laseinde, 2023). For today's organisations, modern supply chains are viewed as a significant source of value. This value can be improved through strategic supply chain management, extending beyond just providing information, goods, and services to create more sustainable forms of value for a wide range of stakeholders. In fact, the realm of supply chain management is consistently experiencing significant changes as growing uncertainty, volatility, and risks present numerous challenges in the global business environment (Nadira Abdul Rasib, 2023).

The emergence of blockchain technologies is altering how traditional supply chains are managed. Given the complexity of dealing with numerous actors involved in supply chain networks, modern supply chains have limited visibility, transparency, and accountability. Consequently, supply chains are increasingly confronting the challenge of integrity and sustainability. Accordingly, blockchain technologies can play a key role in improving the traceability, accountability, and sustainability of complex supply chain networks (Ahmed Khan et al., 2022). In the context of industry, the term "Industry 4.0" is used to describe the fourth industrial revolution. Its emergence is bringing about a dynamic change in industrial operations, systems, and processes that incorporates the adoption of new technologies in manufacturing to enhance maximum efficiency with minimal resource consumption (Asaturova, 2019). The fourth industrial revolution also illustrates smart manufacturing, a system that simplifies hybrid manufacturing through digitalisation, as experienced in the 21st century. The current array of automated technologies utilised in industries consists of cloud computing (CC), Internet of Things (IoT), and cyber-physical systems (CPS) (Ajayi & Laseinde, 2023).

The automation of systems and processes in the supply chain management industry has become increasingly strategic for manufacturing companies, influencing standards, industry models, and organisational boundaries (Herold et al., 2021). The Internet of Things (IoT) is empowering the connected world by facilitating connectivity between disparate objects, including physical devices, sensors, controllers, and intelligent computer processors. Gartner's report predicted that by 2020, there would be up to 5.8 billion IoT endpoints deployed in enterprises and the automotive sector. An increasing number of organisations are starting to adopt IoT, emphasising the business outcomes of the technology. A research report revealed that 71% of companies are collecting data for IoT initiatives (Gartner Report, 2020).

The petrochemical industry plays a crucial role in the energy structure and global economy, and planning at both the strategic and operational levels of its supply chain is aimed at improving the competitive position of nations worldwide and fostering economic development (Zarrinpour & Omdvari, 2020). Capabilities of supply chains, such as sharing information with partners, can greatly enhance supply chain performance (Mehri Babadi et al., 2022). A successful supply chain strategy should specify how to manage the entire path a product undertakes, from the pre-production phase until it reaches the end customer. It should also clarify all aspects associated with activities such as production, supplier management, inventory control, and transportation.

However, despite the growing body of literature on Industry 4.0 technologies and supply chain transformation, prior studies have largely overlooked the integrated evaluation of both capabilities and limitations within a specific industrial context—particularly in the petrochemical sector. Existing research tends to focus on isolated technological benefits or general strategic models, without offering a structured framework that accounts for sector-specific constraints such as infrastructure rigidity, regulatory complexity, and human resource limitations. Moreover, few studies have operationalised these dimensions through measurable indicators that can guide managerial decision-making.

Despite the growing body of research on Industry 4.0 technologies and supply chain transformation, existing studies have rarely offered a strategic framework that simultaneously evaluates both the capabilities and limitations of industrial supply chains—particularly in complex and capital-intensive sectors such as petrochemicals. Prior research has often focused on isolated technological benefits or general performance metrics, without integrating structural constraints such as financial rigidity, organisational complexity, and technological gaps. Moreover, the petrochemical industry, despite its strategic importance, has received limited attention in terms of tailored supply chain strategy models that reflect its operational realities and readiness for Industry 4.0 adoption.

Accordingly, the objective of this study is to design a supply chain management strategy model to evaluate the capabilities and limitations of the petrochemical industry using the In4 (Industry 4.0) approach. The model aims to conceptually integrate enabling factors—such as flexibility, transparency, innovation, and coordination—with structural constraints, including financial, technological, organisational, and human resource limitations, thereby providing a diagnostic framework for strategic alignment. Based on this objective, the central research question is: How can a supply chain management strategy model be designed to evaluate the capabilities and limitations of the petrochemical industry using the In4 approach?

2. Theoretical foundations and research background

In today's globalised and technology-driven economy, supply chains have evolved into strategic ecosystems where competition increasingly occurs between networks rather than individual firms (Jamali & Karimi-Asl, 2018). This transformation has elevated supply chain management (SCM) to a central role in enhancing organisational competitiveness, agility, and sustainability. As information and communication technologies advance, organisations gain greater capacity to collect, update, and utilise data for improved control and decision-making (Adolf et al., 2017). SCM is thus recognised as a deliberate and informed effort to optimise the flow of materials, information, and financial resources across interconnected entities (Meyer, 2020).

A standard supply chain comprises suppliers, manufacturers, distributors, retailers, and end consumers, with the overarching goal of synchronising supply and demand. Enterprise resource planning systems support this integration by improving efficiency, reducing waste, and optimising inventory and operational processes. However, the increasing complexity of global supply chains has exposed firms to new challenges, including limited visibility, fragmented coordination, and vulnerability to disruptions.

Technological innovations—particularly those associated with Industry 4.0—have further transformed supply chains by enabling real-time data exchange, automation, and intelligent decision-making (Ajayi & Laseinde, 2023). Industry 4.0 technologies such as IoT, blockchain, cloud computing, artificial intelligence, and cyber-physical systems have introduced new paradigms for supply chain integration. These technologies enhance visibility, traceability, and responsiveness across supply chain networks, while also supporting digital transformation and business innovation (Anastasia et al., 2024). The Fourth Industrial Revolution facilitates seamless communication among devices, machines, and systems, enabling dynamic reconfiguration of production lines and improved supply chain agility (Eslami et al., 2021; Kazancoglu et al., 2022; Khan et al., 2023).

Recent studies have emphasised the strategic potential of these technologies. For instance, Matarneh et al. (2024) demonstrated how integrating green and sustainable supply chain practices with Industry 4.0 and circular economy principles can enhance corporate sustainability. Bahadur Kunwar (2024) proposed a blockchain-enabled architecture using IoT and smart contracts to improve anomaly detection and transaction security in 6G-enabled supply chains. Raj et al. (2024) showed that effective implementation of Industry 4.0 technologies positively influences marketing performance, particularly through product customisation and customer loyalty. Ajayi & Laseinde (2023) conducted a comprehensive review of supply chain strategies under the Fourth Industrial Revolution, identifying both opportunities and threats associated with digital transformation.

In the Iranian context, several studies have explored the application of digital technologies in supply chain performance. Alyasin et al. (2023) examined the impact of blockchain investment on supply chain agility and competitive advantage in Tehran Stock Exchange-listed firms, using structural equation modelling. Their findings confirmed that blockchain enhances compatibility, alignment, and responsiveness, ultimately improving firm performance. Ranjbar Malekshah et al. (2023) investigated blockchain attributes in the vegetable oil supply chain, identifying key utility factors such as transparency, timely order fulfilment, and data immutability. Mehri Babadi et al. (2022) introduced a performance evaluation model for large-scale oil and gas supply chains, highlighting the role of risk management culture, ISO 14001 certification, and long-term market orientation. Keyghobadi (2021) developed a sustainability assessment model for the oil and gas sector, showing that external pressures, managerial readiness, and commitment to sustainability significantly influence sustainable supply chain practices.

Although a wide range of studies have explored the impact of Industry 4.0 technologies on supply chain performance, most have focused either on technological enablers or isolated strategic outcomes. There remains a lack of integrated frameworks that simultaneously consider both operational capabilities and structural limitations—particularly in complex, capital-intensive sectors such as petrochemicals. Existing research often overlooks how constraints such as financial rigidity, outdated infrastructure, human resource gaps, and organisational fragmentation interact with digital transformation efforts. Moreover, few studies have operationalised these dimensions through measurable indicators tailored to the specific context of industrial supply chains in developing economies.

Given this gap, there is a clear need for a comprehensive and context-sensitive framework that evaluates both the enabling and limiting factors of supply chain strategy in the petrochemical sector. Such a framework should be grounded in the realities of industrial operations, informed by expert insights, and aligned with the technological imperatives of the Fourth Industrial Revolution. By synthesising the theoretical foundations and empirical findings of prior research, the present study aims to address this gap by proposing a dual-perspective strategic model—one that can guide future empirical investigations and support decision-makers in navigating the complexities of supply chain transformation in the petrochemical industry.

3. Research methodology

Given that the objective of this study is to introduce a strategic supply chain management model to evaluate the capabilities and limitations of the petrochemical industry using the In4 approach, the research method is applied in terms of purpose, qualitative in terms of data type, and cross-sectional regarding the timing of data collection. Additionally, the study is classified as a descriptive survey based on its methodological orientation and nature of inquiry.

Among various qualitative research designs, a categorisation-based exploratory approach was adopted. In this design, qualitative data were initially collected through open and semi-structured interviews with domain experts. The statistical population of this study comprises professionals affiliated with Iran's petrochemical industry. Participants included senior industry experts and university professors with substantial academic credentials and practical experience in supply chain management and industrial operations.

Sampling was conducted using purposive judgmental sampling, which is appropriate for exploratory qualitative studies where depth of insight is prioritised over breadth. The selection criteria included: (1) a minimum of ten years of experience in petrochemical supply chain operations or research, (2) demonstrated expertise in strategic planning or industrial systems analysis, (3) familiarity with digital transformation or sustainability initiatives in the sector, and (4) willingness to engage in reflective dialogue on systemic capabilities and constraints.

A total of ten individuals were selected. Although this number may appear limited given the scale and diversity of the petrochemical industry, it is justified by the principle of theoretical saturation. In qualitative research, especially within expert-driven frameworks, the richness of data and convergence of themes are prioritised over sample size. Given the focused scope of this study and the depth of interviews conducted, the number of participants was sufficient to extract stable and recurring patterns relevant to the research objectives.

To analyse the interview data, thematic analysis was employed. Thematic analysis is a method for identifying, analysing, and interpreting patterns (themes) within qualitative data.

At its foundational level, it organises and describes data in detail; at a more advanced level, it enables interpretation of latent meanings and systemic relationships. Given the complexity and contextual sensitivity of qualitative inquiry in industrial domains, thematic analysis was deemed appropriate for capturing the nuanced perspectives of experts. Figure 1 illustrates the six stages of thematic analysis applied in this study.

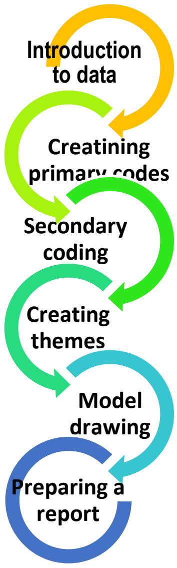

Fig. 1 - Steps to perform a thematic analysis

4. Findings

In examining the average age of the experts interviewed, it was found that university professors and experts with a mean age of 50.66 years had the highest age group, while the managers of the petrochemical industry with a mean age of 46.33 years had the lowest age group. In examining the average work experience, it was determined that university professors and experts with a mean work experience of 20.40 years had the highest experience, while the petrochemical industry managers, with a mean work experience of 16.25 years, had less work experience compared to the university professors and experts. Among the participants in the present study, 6 people held a PhD and 4 people had master's degrees.

Table 1- Demographic characteristics of the experts interviewed

Group	Number	Mean age	Mean work experience	Education	
				Master’s degree	PhD
Petrochemical industry managers	5	46.33	16.25	80%	20%
University professors	5	50.66	20.40	-	100%

A sample transcript of an interview used in this study is shown in Table 2 below.

Table 2- A sample interview transcript

Interview transcript
"I believe that the connectivity and data transfer limitations in the petrochemical industry can be a significant factor negatively impacting the effectiveness of supply chain management strategies in line with the Fourth Industrial Revolution. Connectivity and data transfer limitations may cause delays in information and data flow, which can reduce flexibility and speed of response to various changes in the supply chain and lower efficiency. Due to incomplete access to data, the capacity to effectively leverage it and employ data analytics for enhancing processes and making improved decisions could be restricted. Incomplete connectivity or limitations in data transfer can result in disruptions in the coordination of various elements within the supply chain, causing inefficiencies and reduced overall supply chain efficiency."

Primary and secondary coding: Based on the interview transcriptions, the primary and open codes were initially extracted, followed by the extraction of secondary codes derived from the primary codes. Secondary codes in the thematic analysis method denote the themes, concepts, and patterns identified in the transcriptions to express and describe existing themes and patterns. These codes function as indications that researchers use in the thematic analysis process to identify and categorise similar patterns. Table 3 presents the secondary codes derived from the primary and secondary codes extracted from the interviews conducted in this study.

Table 3- Extracted secondary codes

Row	Extracted secondary codes	Primary and open extracted codes
1	Connectivity and data transfer limitations in the petrochemical industry	Connectivity and data transfer limitations Delays in decision-making Delays in the flow of information and data Inability to use data Disruption in coordination among supply chain members Incomplete connectivity or data transfer limitations Increased security risks due to data connection limitations Attackers are exploiting weaknesses in connections Lower use of technology
2	Security limitations for sensitive supply chain data	Security limitations Threat to the security of sensitive data related to the supply chain Lack of trust in supply chain data and processes Reduced flexibility in processes and decision-making Emergence of changes and new demands in the supply chain Increased costs to ensure the security of data and processes Limitations in communication and information exchange between supply chain members
3	Limitations related to compatibility and integrity between supply chain members	Compatibility and Integrity Limitations Communication failures due to a lack of compatibility and integrity between supply chain members Misalignment of processes due to a lack of compatibility and integrity between supply chain members Lack of flexibility due to a lack of compatibility and integrity Increased costs due to a lack of compatibility and integrity Reduced trust due to a lack of compatibility and integrity

Row	Extracted secondary codes	Primary and open extracted codes
4	Limited investment in infrastructure	Limited investment in infrastructure Reduced technology updates due to insufficient investment in infrastructure Increased security risks due to old and inappropriate infrastructure Reduced productivity due to a lack of appropriate investment in infrastructure Waste of resources, delays in processes and increased production costs Limited development and growth due to a lack of investment in infrastructure Reduced trust and relationships due to inappropriate infrastructure
5	Budget constraints for implementing changes	Budget constraints to implement changes Reduced ability to innovate due to budget constraints Reduced the speed of implementing changes due to budget constraints Increased risks due to the inability to implement changes due to budget constraints Reduced quality due to budget constraints Reduced flexibility due to lack of access to sufficient financial resources
6	Restrictions on global financial communications	Restrictions on global financial connections Reduced access to financial resources due to restrictions on global financial connections Increased financial costs and difficulties due to a lack of access to financial resources Reduced predictability and risk management due to restrictions on global financial connections Reduced ability to invest in innovation due to a lack of access to financial resources Reduced trust and cooperation due to restrictions on global financial connections
7	Time constraints on the distribution and supply of materials	Time constraints on the distribution and supply of materials Increased costs due to time constraints Reduced flexibility due to the inability to supply and distribute materials on time Reduced quality of services and products due to time constraints Reduced ability to innovate due to time constraints Increased risks due to the inability to supply and distribute materials on time
8	Time constraints for organisational changes	Time constraints for organisational changes Delays in implementation due to time constraints for organisational changes Reduced focus and commitment due to time constraints for organisational changes Inability to continuously improve due to time constraints for organisational changes Increased stress and disability due to time constraints for organisational changes Reduced flexibility due to time constraints in dealing with environmental and technological changes
9	Time constraints on information transfer	Time constraints in information transfer Delay in decision-making due to time constraints in information transfer Reduced accuracy and precision of information due to delayed information transfer Increased costs due to delayed information transfer Reduced flexibility due to delayed information transfer Reduced response speed due to time constraints in information transfer
10	Limitations due to the lack of skills and expertise of employees	Limitations due to the lack of skills and expertise of employees Reduced quality and accuracy due to a lack of skills and expertise Increased costs due to the lack of skills and expertise of employees Reduced ability to innovate due to a lack of skills and expertise Reduced flexibility due to the lack of skills and expertise of employees Increased risks and errors due to the lack of skills and expertise of employees
11	Limitations in transformational leadership	Limitations in transformational leadership Reduced employee motivation due to a lack of transformational leadership Reduced trust and cooperation due to the lack of competent or unsuccessful leadership Lack of proper guidance and direction due to a lack of transformational leadership Lack of accurate communication and transfer of goals due to incompetent leadership Inability to adapt to changes due to a lack of transformational leaders
12	Work Overload	Work overload Increased errors and fluctuations due to work overload Reduced focus and attention due to time and ability for work overload Increased stress and fatigue due to work overload Reduced productivity and performance due to increased work overload Reduced vitality and creativity due to work overload

Row	Extracted secondary codes	Primary and open extracted codes
13	The existence of a complex organisational structure in the petrochemical industry	Complex organisational structure Reduced rapid decision-making due to complex structures Reduced flexibility due to complex organisational structures Increased costs due to complex structures Reduced effective communication due to complex structures Reduced ability to monitor and control due to complex organisational structures
14	Too much central control	Too much central control Reduced flexibility due to too much central control Delayed decision-making due to too much central control Reduced innovation and creativity due to too much central control Slow execution due to too much central control Reduced interactions and coordination due to too much central control
15	Organisational culture mismatch with changes	Organisational culture mismatch with changes Reduced employee motivation and commitment due to organisational culture mismatch with changes Weakness in transferring values and goals due to organisational culture mismatch with changes Resistance to change due to organisational culture mismatch Reduced coordination and cooperation due to organisational culture mismatch Reduced flexibility due to an inappropriate organisational culture
16	Sustainable supply of raw materials	Reduced raw material supply risks with sustainable raw material sourcing Increased flexibility with access to resources Achieving sustainability goals with sustainable raw material sourcing Increased quality and reliability with sustainable raw material sourcing from global sources Increased collaboration and partnership by establishing direct and sustainable relationships with global suppliers
17	Quick response to changes in customer demands	Changes in customer demand for your products Increased flexibility in providing services with changes in customer demand Reduced delivery time with changes in customer demand Use of technology and data mining in changes in customer demand Dynamic demand in changes in customer demand
18	Risk management in the supply chain	Risk Management in the Supply Chain in the Petrochemical Industry Reducing the Probability of Risks with Risk Management Identifying, Assessing, and Reducing the Probability and Impact of Various Risks in the Supply Chain Increasing Robustness and Sustainability with Risk Management Creating a More Resilient and Sustainable System in the Supply Chain Improving Planning with Risk Management Increasing Flexibility with Risk Management Increasing Trust with Risk Management
19	Maintaining healthy relationships with suppliers in the petrochemical industry	Maintaining effective and healthy relationships with suppliers Ensuring a stable supply of raw materials and other services required by the petrochemical industry Reducing the possibility of interruptions and delays in the supply chain Sharing knowledge and innovation Reducing costs and improving quality by establishing effective relationships with suppliers More flexibility by maintaining effective relationships with suppliers Improving trust and commitment by maintaining effective relationships with suppliers
20	Cost optimisation in the petrochemical industry supply chain	Cost optimisation in the petrochemical industry supply chain Reducing costs by optimising costs Reducing operating costs in the supply chain Improving the competitive ability of organisations in the petrochemical industry Increasing financial capability by reducing costs Increasing quality and performance by optimising costs Increasing flexibility by reducing costs Achieving sustainable strategies by optimising costs

Row	Extracted secondary codes	Primary and open extracted codes
21	Responding to environmental changes in the petrochemical industry	Responding to Environmental Changes in the Petrochemical Industry More Flexibility by Responding to Environmental Changes Improving Sustainability by Anticipating and Responding to Environmental Changes Increasing Operational Efficiency by Responding to Environmental Changes Promoting Innovation by Environmental Changes Compliance with Standards by Environmental Changes
22	Better organisation and process improvement in the petrochemical industry	Better organisation and process improvement in the petrochemical industry Increased productivity with better organisation and process improvement Reduced costs by optimising and improving processes Reduced delivery time with better organisation and process improvement Increased quality by modifying processes and improving organisation Realising innovative strategies with better process improvement and organisation Promoted innovative and advanced strategies in the field of supply chain management
23	Development of new processes and technologies in the petrochemical industry	Development of new processes and technologies in the petrochemical industry Increased automation using new technologies Improved tracking and tracing using new technologies such as barcoding Improved process coordination by developing new technologies Advances in forecasting and decision-making using advanced data analysis and artificial intelligence Improved security by utilising new technologies to maintain security in the supply chain
24	Developing innovative products in the petrochemical industry	Development of innovative products in the petrochemical industry Increasing the added value of products by developing innovative products Reduced product development time by utilising new technologies Increased flexibility with innovative products Improved coordination with the supply chain by developing innovative products leads to Reduced costs with innovative products Promoting sustainability by developing innovative products
25	Coordination of infrastructure and processes in the petrochemical industry	Coordination in Infrastructure and Processes in the Petrochemical Industry Improved communications due to coordination in infrastructure and processes Increased responsiveness due to coordination in infrastructure and processes Reduced delays and overheads due to proper coordination, delays and overheads in processes Improved demand and supply coordination due to coordination in infrastructure and processes Optimum use of technology due to coordination in infrastructure and processes
26	Coordination of innovative strategies in the petrochemical industry	Coordination in innovative strategies in the petrochemical industry Adapting to market needs with coordination in innovative strategies Facilitating the innovation process with appropriate coordination of innovative strategies Using advanced technologies with coordination in innovative strategies Facilitating cooperation and coordination in innovative strategies Reducing costs and development time with coordination in innovative strategies
27	Coordination with suppliers in the petrochemical industry	Coordination with suppliers in the petrochemical industry Ensuring the provision of required resources by coordinating with suppliers Reduced risks and fluctuations by coordinating with suppliers Improving quality and innovation through coordination with suppliers Increased cooperation and interaction through coordination with suppliers Reduced costs and improved delivery time through coordination with suppliers
28	Development of supply chain quality in the petrochemical industry	Development of supply chain quality in the petrochemical industry Reduced errors and material waste by developing supply chain quality Ensuring the sustainability of material supply by increasing supply chain quality Improved standards and processes by developing supply chain quality Use of new technologies to improve supply chain quality Reduced costs and delivery time by developing supply chain quality

Row	Extracted secondary codes	Primary and open extracted codes
29	Creating long-term relationships in the petrochemical industry supply chain	Creating long-term relationships in the petrochemical industry supply chain Building trust and sustainability by creating long-term relationships with suppliers Exchanging information and knowledge by creating long-term relationships with suppliers Developing cooperation and liquidity by creating long-term relationships with suppliers Committing to long-term cooperation by creating long-term relationships with suppliers Reduced costs and improved quality by creating long-term relationships with suppliers
30	Increased quality of product offerings in the petrochemical industry	Increased quality of product offerings in the petrochemical industry Increased customer satisfaction by increasing product quality Reduced material waste and increased productivity by providing quality products Strengthening relationships with suppliers by increasing product quality Use of new technologies to increase product quality Reduced costs and delivery time by increasing product quality

Table 5 reports the themes obtained from the extracted secondary codes.

Table 5- Themes obtained from the extracted secondary codes

Row	Objective	Main Theme	Sub-theme	Extracted secondary codes
1	Supply chain management strategy to evaluate the capabilities and limitations of the petrochemical industry with the In4 approach	Limitations	Technology limitations	Connectivity and data transfer limitations in the petrochemical industry
2				Security Limitations for Sensitive Supply Chain Data
3				Limitations related to compatibility and integrity between supply chain members
4			Financial limitations	Limited investment in infrastructure
5				Budget constraints for implementing changes
6				Time constraints on information transfer
7			Time Limitation	Restrictions on global financial communications
8				Time constraints for organisational changes
9				Time constraints on information transfer
10			Human resource limitations	Limitations due to the lack of skills and expertise of employees
11				Limitations in transformational leadership
12				Work overload
13			Organizational limitations	The existence of a complex organisational structure in the petrochemical industry
14				Too much central control
15				Organisational culture mismatch with changes
16		Capabilities	Supply chain flexibility	Sustainable supply of raw materials
17				Rapid response to changes in customer demand
18				Risk management in the supply chain
16			Supply chain sustainability	Maintaining Effective and Healthy Supplier Relationships in the Petrochemical Industry
20				Optimising Costs in the Petrochemical Industry Supply Chain
21				Responding to Environmental Changes in the Petrochemical Industry
22			Supply chain innovation	Better organisation and process improvement in the petrochemical industry

Row	Objective	Main Theme	Sub-theme	Extracted secondary codes
23				Development of new processes and technologies in the petrochemical industry
24				Development of innovative products in the petrochemical industry
25			Supply chain coordination	Coordination in infrastructure and processes in the petrochemical industry
26				Coordination in innovative strategies in the petrochemical industry
27				Coordination with suppliers in the petrochemical industry
28			Transparency in the supply chain	Developing the quality of the supply chain in the petrochemical industry
29				Establishing long-term relationships in the petrochemical industry supply chain
30				Increasing the quality of product offerings in the petrochemical industry

In this research, according to the opinions of experts and ultimately the primary and secondary codes, two main dimensions, including limitations and capabilities, emerged. Moreover, 191 primary codes were extracted from 10 interviews, leading to the identification of 30 secondary codes and 10 themes. The ultimate research model is illustrated in Figure 2.

To ensure the trustworthiness of the extracted model, the study followed established qualitative criteria. Credibility was achieved through purposive sampling of ten senior experts in petrochemical supply chain management, and thematic saturation was confirmed by the eighth interview. Dependability was ensured by applying Braun and Clarke's six-phase thematic analysis framework, with independent coding conducted by two researchers. Coding consistency was evaluated using Cohen's Kappa, yielding an average coefficient of $\kappa = 0.82$, which indicates substantial agreement and supports the reliability of the thematic structure. Confirmability was maintained through audit trails and reflexive memoing, and transferability was supported by clearly defining the industrial context and sampling boundaries. These procedures collectively confirm the methodological rigour of the model, which conceptually integrates supply chain capabilities and limitations under the In4 framework.

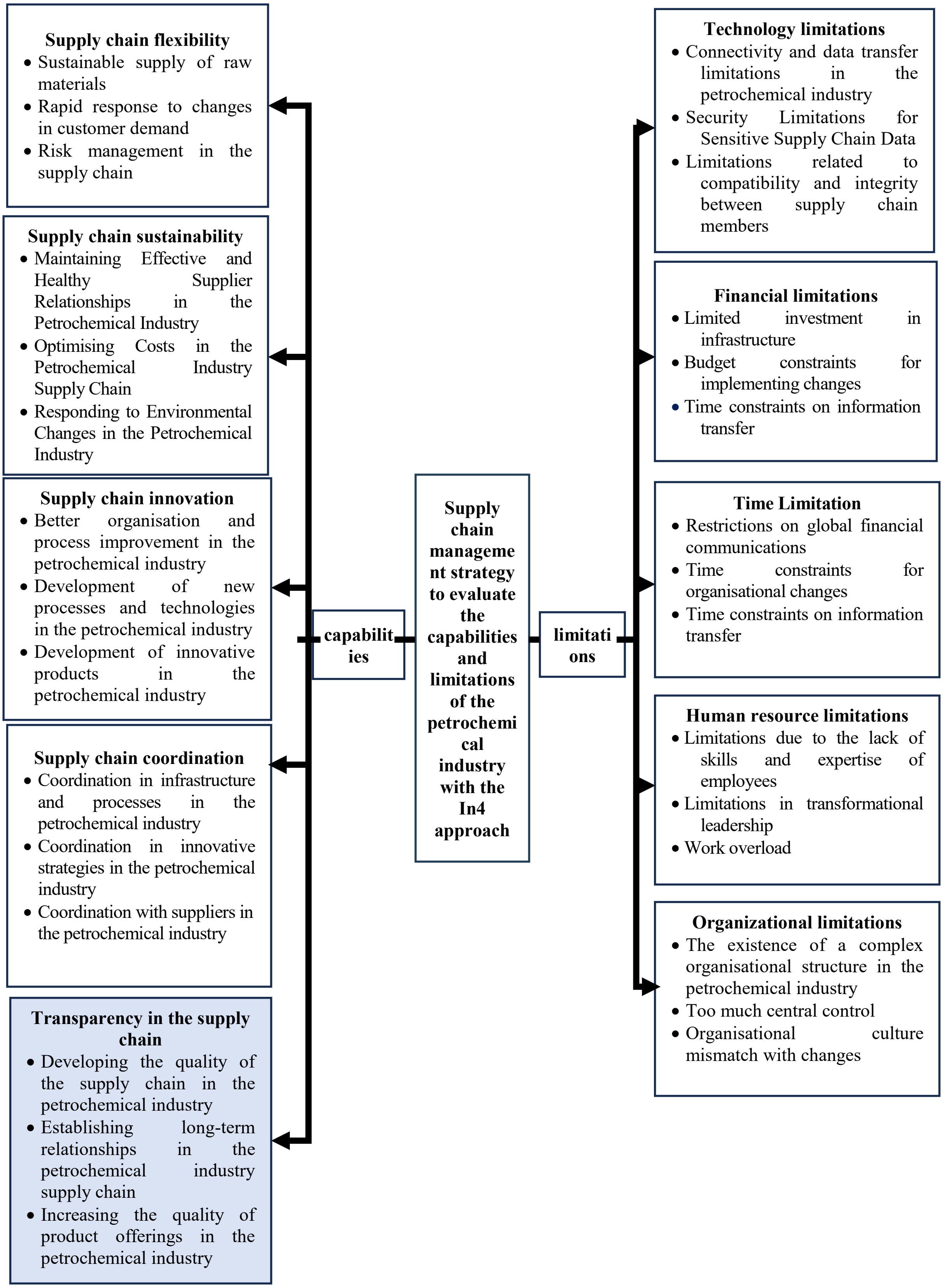

Fig. 2- Final model obtained from secondary research codes

5. Discussion

The purpose of this study was to develop a strategic framework for supply chain management in the petrochemical industry, using the In4 approach to systematically assess both operational capabilities and structural limitations. Through thematic analysis of expert interviews, five core capabilities were identified: supply chain flexibility, sustainability, innovation, transparency, and coordination. These dimensions were operationalised through specific indicators, enabling firms to evaluate their current performance and identify targeted improvement areas.

The findings of this study are broadly consistent with existing literature, yet they extend it in several critical directions. For instance, Matarneh et al. (2024) emphasised supply chain flexibility as a key factor in adapting to market volatility, which this study confirms and contextualises within the operational dynamics of petrochemical firms. Similarly, Raj et al. (2024) and Ajayi & Laseinde (2023) underscored sustainability and innovation as strategic imperatives for long-term competitiveness and environmental compliance. Our framework reinforces these priorities while introducing measurable indicators tailored to the logistics, production, and regulatory realities of the petrochemical sector.

Transparency, as discussed by Alyasin et al. (2023), was framed as a mechanism for enhancing stakeholder trust and regulatory alignment. This study builds on that by identifying traceability tools—such as blockchain and IoT—not merely as conceptual enablers but as operational levers for improving visibility and accountability across supply chain tiers. Coordination, previously explored by Mehri Babadi (2022), is reconceptualised here through its linkage to cross-functional integration and supplier collaboration metrics, offering a more actionable understanding of inter-organisational alignment.

The principal innovation of this research lies in its integrated, indicator-based framework that simultaneously evaluates both enabling capabilities and structural limitations—an approach largely absent in prior studies. While earlier models often treated these dimensions as separate or generalised constructs, this study introduces a dual-perspective structure grounded in expert-driven thematic analysis and contextualised within Industry 4.0 imperatives. The identified limitations—technological, financial, temporal, human resource, and organisational—are not only categorised but also operationalised through 15 specific indicators, allowing firms to diagnose systemic bottlenecks and prioritise strategic interventions.

This integrative framework contributes to the literature by bridging strategic theory with operational diagnostics. It moves beyond descriptive typologies and offers a structured tool for assessing readiness, identifying constraints, and aligning supply chain strategies with sector-specific transformation goals. Its methodological rigour, sectoral specificity, and practical relevance make it a valuable resource for managers, consultants, and policymakers seeking to enhance supply chain resilience, agility, and competitiveness in volatile industrial environments.

Future research may build on this framework by applying it across comparative contexts—such as public versus private petrochemical firms—or by integrating quantitative validation techniques to assess the predictive power of the identified indicators. Moreover, the evolving role of digital technologies in enabling transparency, coordination, and innovation warrants deeper investigation, particularly in relation to regulatory compliance, workforce development, and sustainability metrics.

6. Conclusions

This study presents a strategic framework for petrochemical supply chain management that integrates both capability enhancement and limitation mitigation. The proposed model, grounded in expert insights and thematic analysis, offers a practical roadmap for aligning supply chain strategies with sector-specific realities.

Based on the findings, the following recommendations are proposed:

- Implement agile practices to improve responsiveness to market dynamics and customer needs.
- Invest in research and development to foster innovation and reduce environmental impact.
- Utilise emerging technologies such as blockchain and IoT to enhance traceability and transparency.
- Upgrade digital infrastructure to support automation, data analytics, and real-time decision-making.
- Conduct thorough financial assessments before launching new projects to ensure fiscal sustainability.
- Promote continuous workforce development to address skill gaps and retain talent.
- Streamline supply chain processes to eliminate bottlenecks and reduce delays.
- Establish and monitor key performance indicators to track progress and identify areas for improvement.

Despite its contributions, this study is subject to several limitations that should be acknowledged. First, the sample size was limited to ten experts, which may constrain the generalizability of the findings across diverse petrochemical contexts. Second, the reliance on qualitative thematic analysis, while rich in insight, may benefit from triangulation with quantitative methods to enhance robustness. Third, the framework was developed within a specific national and industrial context, and its applicability to other regions or sectors requires empirical validation.

It is recommended that future researchers explore the role of emerging technologies such as the Internet of Things and blockchain in enhancing transparency and traceability within Iran’s petrochemical supply chains, with particular attention to indicators related to regulatory compliance and supplier trust. Scholars are encouraged to investigate the relationship between supply chain flexibility and operational resilience in Iranian petrochemical companies, especially in response to domestic market fluctuations and external sanctions, in order to identify effective agility-enhancing strategies. Future studies should assess the effectiveness of human resource training and development programs in reducing skill-based limitations and improving workforce productivity across technical and managerial functions in Iran’s petrochemical supply chain. It is suggested that comparative research be conducted between public and private petrochemical firms in Iran to empirically evaluate the role of inter-organisational coordination mechanisms in improving supply chain performance and mitigating structural constraints.

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