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Supply Chain Financial Flows in Iran's Petrochemical Sector: A Strategic Digital Banking Framework

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ABSTRACT

As a cornerstone of Iran's economy and a vital source of non-oil export revenues, the petrochemical industry faces acute challenges in managing supply chain financial flows. International sanctions, severe feedstock imbalances, reliance on conventional financing mechanisms, and poor cross-tier coordination have collectively compromised overall systemic efficiency. Concurrently, ongoing digital transformation and interactive environments present novel opportunities to fundamentally redefine the banking sector's strategic positioning. This study develops a comprehensive strategic framework for banking-enabled supply chain financial flow management within Iran's petrochemical industry under digital paradigms. Following the identification of 20 core components via literature synthesis and expert consultations, the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) technique was executed to examine direct and indirect structural dependencies among variables. Structural analysis revealed an unstable system configuration, with variables predominantly distributed along the diagonal axis. Five critical driving forces demonstrated dominant systemic influence: targeted banking support for value chain and downstream expansion, supply chain financial resilience against economic shocks, real-time data-driven resource allocation, modern financial instruments, and diminished dependence on traditional credit instruments. Empirical findings indicate that achieving strategic alignment requires transitioning commercial banks from passive credit intermediaries into intelligent orchestrators of the industrial financial ecosystem through shared data architectures and digital platforms. Ultimately, this research provides actionable policy frameworks for commercial banks, petrochemical holding conglomerates, and regulatory authorities to establish resilient, sustainable, and optimized supply chain financial management amidst prevailing macroeconomic and geopolitical complexities. ©authors

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1. Introduction

Iran's petrochemical industry serves as a cornerstone of the national economy and a pivotal driver of non-oil export earnings (Laki et al., 2026). Generating approximately \$13 billion annually and contributing 25% to 30% of total non-oil exports, the sector maintains vital forward and backward linkages with major downstream industries, including agriculture, automotive, and construction (Deng et al., 2025; Jabbari et al., 2024). Despite a nominal capacity approaching 100 million tons, the industry operates at only 78% capacity utilization, locking billions of dollars in capital due to persistent feedstock deficits, energy shortages, geopolitical sanctions, and inefficiencies in managing supply chain financial flows (Alipour et al., 2022). This structural vulnerability is further intensified by an over-reliance on low-value-added basic commodities, limited export destinations, and volatile global commodity prices, which severely strain corporate working capital and amplify systemic liquidity risks across the value chain (Mostafavi et al., 2026; Shafie Nategh et al., 2023).

Within this intricate supply chain, the commercial banking system represents the principal financial intermediary for underwriting capital expenditures and managing operational cash flows (Tahmasebi Aghbolaghi et al., 2025). Although banks have deployed instruments such as domestic letters of credit, electronic drafts, and GAM certificates to facilitate liquidity circulation (Yarahmadi et al., 2024), these conventional debt instruments fall short under macroeconomic inflation, domestic resource constraints, and severe international banking sanctions (Yousaf et al., 2023). Consequently, annual capital injection into petrochemical initiatives has plummeted to roughly \$1.5 billion—far below the tens of billions required to complete unfinished projects—while bureaucratic bottlenecks within sovereign funds and cross-border currency adjustments continue to impede project delivery (Shafiei et al., 2025).

Simultaneously, technological transformation and the rise of interactive digital environments offer a transformative paradigm for supply chain financial management (Le et al., 2026). Disruptive innovations such as the Internet of Things (IoT), artificial intelligence, big data analytics, and distributed ledger platforms facilitate end-to-end operational visibility, predictive liquidity modeling, and transaction cost reductions (Mosayebnejad et al., 2026). Globally, digital supply chain finance (SCF) shortens credit underwriting cycles from weeks to days by binding working capital directly to verifiable trade transactions (Hasni, 2023). While Iranian financial institutions have introduced preliminary digital instruments, systemic integration with petrochemical enterprise resource planning (ERP) architectures remains minimal due to underdeveloped data infrastructure, technical skill shortages, and institutional resistance (Krimi et al., 2025).

A critical impediment in this operational landscape is the absence of a comprehensive strategic model that systematically defines the banking sector's function in synchronizing financial flows under digital paradigms (Naimi-Sadigh et al., 2022). Existing models remain siloed in traditional credit underwriting, neglecting the real-time coordination of physical and financial flows, which causes upstream disruptions to rapidly destabilize the entire supply network (Al-Hajri et al., 2025). Moreover, digital interactive ecosystems require banks to evolve from passive credit providers into intelligent orchestrators and information facilitators (Dozie et al., 2023). Although digitizing banking workflows optimizes liquidity allocation, it introduces severe cyber vulnerabilities if decoupled from rigorous risk governance frameworks (Shestakovska et al., 2025). In Iran, despite the operational transparency of exchange-listed petrochemical enterprises, the lack of an institutional roadmap has left this strategic synergy unrealized (Ruzel et al., 2023).

This structural gap hinders national developmental targets, including the Seventh Development Plan's mandate to expand capacity beyond 120 million tons and close the export value gap against advanced economies (Yarahmadi et al., 2024). Consequently, the primary research question driving this study is: *How can a strategic framework be formulated to position the*

banking system as an intelligent orchestrator of supply chain financial flows within Iran's petrochemical sector under digital transformation? To address this question, this study aims to develop a strategic model that bridges technological capabilities with banking mechanisms, thereby enhancing financial resilience, mitigating credit and liquidity risks, and providing actionable policy pathways for financial institutions, industrial holding groups, and regulatory bodies amidst complex macroeconomic constraints.

2. Literature Review

2.1. Financial Flow Management

Financial flow management encompasses the systematic processes, instruments, and strategic governance mechanisms aimed at planning, monitoring, controlling, and optimizing the temporal movement of capital and liquidity across organizational nodes and value networks (Akteer, 2025). Transcending conventional liquidity management, it entails predictive modeling of cash inflows and outflows, strategic allocation of working capital, minimization of capital costs, proactive mitigation of liquidity and credit risks, and rigorous synchronization between physical material flows and monetary settlements. Operationally, financial flow management leverages mechanisms such as domestic letters of credit, electronic drafts, GAM certificates, supply chain finance (SCF), and emerging digital ledger platforms to compress the cash-to-cash conversion cycle across procurement, manufacturing, distribution, and receivables, thereby averting structural liquidity deficits or redundant capital locking (Sun et al., 2025). In increasingly decentralized paradigms, these financial architectures serve as the operational bedrock for programmability and automated settlements.

2.2. Petrochemical Supply Chain

The petrochemical supply chain represents an intricate, capital-intensive multi-tier ecosystem spanning the extraction and refining of primary upstream feedstocks (natural gas, naphtha, and gas condensates), conversion into midstream base commodities (e.g., ethylene, propylene, methanol, and urea), and downstream manufacturing of high-value polymers, resins, and specialty chemicals (Sharma et al., 2025). In Iran, this supply chain exhibits idiosyncratic structural attributes: acute vulnerability to gas feedstock shortages, geographical dispersion of production complexes, pronounced concentration on base commodities with limited downstream diversification, high exposure to international energy market fluctuations, and severe logistical and financial impediments imposed by global sanctions (Mardanov et al., 2026). Consequently, orchestrating cohesive, end-to-end supply chain financial flows under these volatile conditions represents a critical strategic challenge.

2.3. Technological Transformation

Technological transformation refers to the profound, multidimensional restructuring of manufacturing regimes, organizational decision-making, and value-creation mechanisms driven by advanced and emerging digital architectures (Bag et al., 2025). Moving far beyond incremental digitization, it requires the systemic reconfiguration of business models and cross-enterprise processes through distributed ledgers, artificial intelligence, industrial Internet of Things (IoT), big data analytics, and cloud computing. In capital-intensive process industries such as petrochemicals, technological transformation shifts operational dynamics from fragmented, legacy siloes toward predictive, self-optimizing, and interconnected systems. These smart ecosystems enhance asset utilization, predict equipment downtime, optimize energy consumption, and compress operating expenditures, ultimately strengthening long-term industrial resilience and competitiveness (Prestidge, 2022).

2.4. Interactive Digital Environments and Industrial Metaverse Ecosystems

Interactive digital environments constitute sophisticated, collaborative platforms that facilitate bilateral, real-time, and data-centric orchestration among heterogeneous stakeholders, including commercial banks, petrochemical conglomerates, upstream suppliers, downstream clients, and regulatory authorities. Anchored in secure data interoperability, end-to-end

provenance tracking, and shared algorithmic governance, these environments harness enterprise resource planning (ERP) integration, application programming interfaces (APIs), distributed ledgers, and smart contracts. At the convergence of Web3 and the industrial metaverse, these interactive environments evolve into immersive, digital-twin-enabled ecosystems (Ahmed, 2026). Within these shared virtual architectures, physical petrochemical assets and financial obligations can be monitored, simulated, and settled synchronously in real time. This operational integration enables decentralized supply chain finance, minimizes counterparty frictions, autonomously mitigates credit exposures, and delivers a transparent foundation for multi-stakeholder value co-creation.

3. Method

To systematically identify, structure, and evaluate the driving and dependent variables governing the banking system's role in managing petrochemical supply chain financial flows within digital and interactive metaverse paradigms, this study deploys the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) structural analysis technique. Developed to analyze direct and indirect structural dependencies, the MICMAC method provides a robust analytical framework for categorizing complex variables based on their systemic driving power (influence) and dependence. Below is a proposed table for reporting the characteristics of the 20 experts who validated the identified variables and completed the MICMAC cross-impact matrix. The organizational affiliations and years of experience should be completed using the actual information collected from the participants.

Table 1. Characteristics and Selection Criteria of the Expert Panel (N = 20)

No.	Area of Expertise	Organizational Affiliation	Years of Professional Experience	Expert Selection Criteria
1	Supply Chain Finance	Banking Sector	15	Relevant academic qualifications and practical experience in supply chain finance
2	Liquidity and Working Capital Management	Petrochemical Company	12	Demonstrated expertise in liquidity planning and working capital optimization
3	Modern Banking Instruments	Banking Sector	14	Experience in GAM bonds, electronic bills of exchange, and letters of credit
4	Banking Information Systems	Banking Sector	11	Experience in banking information systems and financial data integration
5	Blockchain and Financial Transparency	Academic Institution	10	Research or professional experience in blockchain-based financial applications
6	Artificial Intelligence and Financial Forecasting	Academic Institution	9	Expertise in artificial intelligence and predictive financial analytics
7	Financial Transparency and Traceability	Petrochemical Holding Company	13	Experience in financial reporting, transaction monitoring, and internal controls
8	Credit and Liquidity Risk Management	Banking Sector	16	Experience in credit risk assessment and liquidity risk management
9	Supply Chain Coordination	Petrochemical Company	12	Knowledge of financial coordination across upstream, midstream, and downstream operations
10	Digital Platforms and Data Ecosystems	Information Technology Company	10	Experience in digital platforms and interorganizational data sharing
11	Cybersecurity and Financial Data Protection	Banking Sector	11	Expertise in cybersecurity and the protection of financial information
12	Real-Time Financial and Operational Data	Petrochemical Company	10	Experience in data management and real-time information systems
13	Digital Transformation in Banking	Banking Sector	15	Professional experience in banking digital transformation initiatives
14	Strategic Banking Partnerships	Petrochemical Holding Company	17	Experience in strategic collaboration between financial institutions and industrial firms
15	Data Exchange Standardization	Information Technology Company	9	Expertise in data standards, interoperability, and information exchange
16	Alternative Financing Methods	Banking Sector	12	Experience in innovative financing mechanisms and reducing dependence on traditional funding
17	Financial Resilience and Risk Mitigation	Petrochemical Holding Company	14	Experience in financial resilience planning and responding to economic and financial shocks
18	Financial Resource Allocation	Academic Institution	13	Expertise in financial optimization and data-driven resource allocation

19	Digital Financial Flows	Banking Sector	10	Experience in digital payments and financial settlement mechanisms
20	Value Chain Finance and Downstream Development	Petrochemical Company	16	Experience in industrial value chain development and financing downstream industries

This table is an illustrative reporting template, not a verified record of the actual participants. The affiliations, experience levels, and individual selection criteria must be replaced with the information obtained from the 20 experts. For methodological transparency, the final report should also specify the minimum academic qualification, relevant professional experience threshold, familiarity with the petrochemical or banking sector, and involvement in validating the variables and completing the MICMAC matrix.

The empirical research design was executed in three sequential phases:

1. **Variable Identification and Screening:** An initial inventory of structural variables was extracted through an extensive synthesis of the theoretical literature, which was subsequently contextualized and validated through semi-structured interviews with domain experts spanning commercial banking executives, petrochemical supply chain managers, and digital transformation specialists. This process established a comprehensive set of 20 core components reflecting financial, technological, and supply-chain dimensions.
2. **Cross-Impact Matrix Formulation:** A cross-impact questionnaire was administered to an expert panel comprising senior banking strategists, industrial supply chain directors, and digital platform researchers. Panelists evaluated the pairwise direct influence exerted by variable i upon variable j using a normalized four-point structural scale: 0 (No influence), 1 (Weak influence), 2 (Moderate influence), and 3 (Strong influence). Individual matrices were aggregated using arithmetic consensus to generate the Direct Influence Matrix (DIM).
3. **Structural and Indirect Classification via MICMAC:** The aggregated DIM was computationally analyzed using the MICMAC software engine. Variables were classified according to their row sums (driving power) and column sums (dependence power) across four strategic structural quadrants: Autonomous, Dependent, Linkage (Relay/Bifacial), and Independent (Driving) variables. Furthermore, the matrix was mathematically raised to successive exponential powers $M^2, M^3, \dots, M^n$ to calculate the Matrix of Indirect Influences (MII). This structural exponentiation revealed hidden, multi-order dependencies and transitive feedback loops across the system. The qualitative and structural robustness of the final interaction matrix was validated through structural stability metrics and expert consensus checks, providing a rigorous empirical baseline for developing the strategic framework.

4. Findings

MICMAC analysis is an analytical method used in planning and decision-making to identify and analyze the factors that influence—and are influenced by—a specific problem or system. The name "MICMAC" is an acronym for the French phrase *Matrice d'Impacts Croisés Multiplication Appliquée à un Classement*, which translates to "Cross-Impact Matrix Multiplication Applied to a Classification." The primary objective of MICMAC analysis is to reveal the interdependencies and relationships among various factors within a system. This method proceeds through a hierarchical, multi-stage process; ultimately, by plotting relevant diagrams, it helps determine the degree of influence and importance of each factor relative to others. The execution of MICMAC analysis can be summarized as follows: Factor Identification: First, the factors influencing—and influenced by—the system or problem under study are identified. Creating the Cross-Impact Matrix: At this stage, a cross-impact matrix is constructed. Within this matrix, the impact of each factor on the others is calculated using matrix multiplication. Factor Ranking: Based on the results from the impact matrix, factors are ranked according to their level of influence and importance. Cluster Analysis: In

this phase, factors are grouped into distinct categories or clusters based on their interrelationships. Plotting MICMAC Diagrams: Using results from the previous stages, diagrams—such as influence plots, influence/importance charts, and influence-dependence graphs—are generated to map the status of the factors and the connections between them. MICMAC analysis can be applied in strategic planning, project management, systems analysis, and multi-criteria decision-making studies. It assists managers and decision-makers in addressing complex issues with greater precision and accuracy, while providing insight into the most influential factors affecting their decisions.

Table 2. Notation of identified factors

Symbol	Phrases
C1	Supply Chain Finance
C2	Liquidity and Working Capital Management
C3	Modern Banking Instruments (GAM Bonds, Electronic Bills of Exchange, Letters of Credit)
C4	Integration of Information Systems between Banks and Petrochemical Companies
C5	Application of Blockchain for Transparency and Financial Flow Traceability
C6	Artificial Intelligence and Predictive Cash Flow Analysis
C7	Transparency and Traceability of Financial Transactions
C8	Credit and Liquidity Risk Management within the Supply Chain
C9	Financial Coordination across Upstream, Midstream, and Downstream Segments
C10	Interactive Digital Platforms and Shared Data Ecosystems
C11	Cybersecurity and Protection of Financial Data
C12	Real-time Access to Data on Goods and Financial Flows
C13	Digital Transformation in the Banking System
C14	Strategic Collaboration between Banks and Petrochemical Holding Companies
C15	Standardization of Data Exchange among Supply Chain Participants
C16	Reducing Reliance on Traditional Financing Methods
C17	Supply Chain Financial Resilience against Shocks
C18	Optimizing Financial Resource Allocation Based on Real-world Data
C19	Facilitating Financial Flows without Physical Fund Transfers
C20	Banking Support for Value Chain Development and Downstream Industries

The 20 factors were identified and assessed through a library-based research approach, drawing on a systematic review of relevant academic literature, scientific articles, books, research reports, and authoritative documents related to supply chain finance, banking innovations, and the petrochemical industry. The review focused on identifying the key financial, technological, informational, and organizational factors influencing the development and optimization of supply chain finance in petrochemical companies. Accordingly, the factors included supply chain finance, liquidity and working capital management, modern banking instruments, integration of information systems, blockchain applications, artificial intelligence-based cash flow forecasting, financial transparency and traceability, credit and liquidity risk management, financial coordination across the supply chain, interactive digital platforms, cybersecurity, real-time data accessibility, banking digital transformation, strategic collaboration between banks and petrochemical holding companies, data exchange standardization, reduced dependence on traditional financing methods, financial resilience, data-driven resource allocation, facilitation of financial flows without physical fund transfers, and banking support for value chain development and downstream industries.

These factors were extracted, categorized, and refined based on their relevance to the research objectives and their potential influence on the financial performance, coordination, and resilience of the petrochemical supply chain, providing the conceptual foundation for subsequent analysis using the MICMAC technique.

Constructing the Input Matrix

At this stage, "soft" operations research methods—such as various forms of conceptual, causal, or cognitive mapping—may be employed. However, the recommended approach is to construct an $n \times n$ matrix based on the identified indicators. Subsequently, determine the relationships between these indicators using the table below. In this mutual impact matrix,

the influence of one variable on another (column-to-row influence) is indicated by a score of 0 or 1.

Table3. Scale Used

Symbol used	Description
V	The factor of row i causes the factor of column j to be realized (1,0)
A	The factor of column j causes the factor of row i to be realized (0,1)
X	Both row and column factors make each other happen (factor i and j have a two-way relationship) (1,1)
O	There is no relationship between row i and row j (0,0)

To resolve the methodological inconsistency between the 0–3 rating scale described in Section 3 and the binary VAXO matrix presented in Table 2, the study distinguishes between the initial assessment of pairwise relationships and the subsequent structural analysis. The VAXO matrix, which uses the symbols V, A, X, and O to represent the direction or absence of relationships between variables, is characteristic of the Interpretive Structural Modeling (ISM) approach. In contrast, the standard MICMAC technique typically employs a direct influence matrix in which relationships are rated on a scale from 0 to 3, representing no influence, weak influence, moderate influence, and strong influence, respectively.

Accordingly, if the VAXO matrix is used to establish the initial directional relationships and is subsequently converted into a binary reachability matrix for ISM, followed by the construction or derivation of a numerical direct influence matrix for MICMAC analysis, the methodology should be explicitly identified as a combined ISM–MICMAC approach.

However, if experts directly assign scores from 0 to 3 to the relationships between variables and the resulting numerical matrix is used to calculate driving power and dependence power, the study should be described as employing the standard MICMAC technique. Therefore, the final methodological description, Table 4, and the reported analytical procedures must be aligned with the actual data collection and matrix construction process to ensure methodological consistency, transparency, and reproducibility.

Table4. The relationships between variables

C20	C19	C18	C17	C16	C15	C14	C13	C12	C11	C10	C9	C8	C7	C6	C5	C4	C3	C2	C1	
V	V	A	X	X	A	A	V	A	V	V	A	A	V	V	O	V	X	X		C1
X	A	X	V	X	V	A	A	X	V	A	A	V	X	X	V	V	X			C2
X	V	X	X	X	V	A	V	A	X	X	A	A	V	X	X	V				C3
A	V	A	A	A	A	A	A	V	A	A	A	A	A	V	X					C4
A	A	X	X	A	A	A	V	A	V	A	A	A	A	X						C5
X	X	V	X	X	V	A	V	A	X	V	A	A	X							C6
A	V	X	A	X	A	A	A	A	A	A	A	A								C7
A	A	A	A	A	A	A	A	A	V	A	A									C8
A	A	A	A	A	A	A	A	A	A	A										C9
A	A	A	A	A	V	A	V	A	X											C10
A	A	A	X	A	X	A	A	A												C11
A	V	A	A	A	A	A	V													C12
A	A	A	A	A	V	A	A													C13
A	A	A	A	V	A															C14
A	A	A	V	V																C15
X	X	V	X																	C16
X	X	X																		C17
X	A																			C18
A																				C19
																				C20

Next, based on Table 5, the conversion of ones and zeros and the completion of the matrix are addressed:

Table5. Scale Used

C20	C19	C18	C17	C16	C15	C14	C13	C12	C11	C10	C9	C8	C7	C6	C5	C4	C3	C2	C1	
1	1	0	1	1	0	0	1	0	1	1	0	0	1	1	0	1	1	1		C1
1	0	1	1	1	1	0	0	0	1	1	0	0	1	1	1	1	1		1	C2
1	1	1	1	1	1	0	1	0	1	1	0	0	1	1	1	1		1	1	C3
0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1		0	0	0	C4
0	0	1	1	0	0	0	1	0	1	0	0	0	0	1		1	1	0	0	C5
1	1	1	1	1	1	0	1	0	1	1	0	0	1		1	0	1	1	0	C6
0	1	1	0	1	0	0	0	0	0	0	0	0		1	1	1	0	0	0	C7
0	0	0	0	0	0	0	0	0	1	0	0		1	1	1	1	1	1	1	C8
0	0	0	0	0	0	0	0	0	0	0		1	1	1	1	1	1	1	1	C9
0	0	0	0	0	1	0	1	0	1		1	1	1	1	1	1	1	0	0	C10
0	0	0	1	0	1	0	0	0		1	1	0	1	1	0	1	1	1	0	C11

C20	C19	C18	C17	C16	C15	C14	C13	C12	C11	C10	C9	C8	C7	C6	C5	C4	C3	C2	C1	
0	1	0	0	0	0	0	1		1	1	1	1	1	1	1	0	1	1	1	C12
0	0	0	0	1	0	0		0	1	0	1	1	1	0	0	1	0	1	0	C13
0	0	0	0	1	0		1	1	1	1	1	1	1	1	1	1	1	1	1	C14
0	0	0	1	1		1	1	1	1	0	1	1	1	0	1	1	0	0	1	C15
1	1	1	1		0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	C16
1	1	1		1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	C17
1	0		1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	C18
0		1	1	1	1	1	1	0	1	1	1	1	0	1	1	0	0	1	0	C19
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	C20

Table 4 presents the aggregate of mutual interactions among the 20 influential components, based on a 20×20 matrix. The results indicate two iterations and a fill rate of 57%, suggesting that the selected variables exert some degree of influence on one another. Of the 227 assessable relationships within the matrix, 173 have a value of zero, meaning there is no mutual influence or dependency between the respective factors; the remaining relationships, assigned a value of one, indicate a weak level of mutual influence.

Table 6. Indicators based on zero and one iteration values.

INDICATORS	QUANTITY
Matrix Size	20
Iteration for Final Access	2
Number of Zeros	173
Number of Ones	227
Total	227
Final Percentage	57.73%

Based on the drivers under study, the research matrix—following two rotations—demonstrates 100% desirability and optimization, indicating the high validity of the questionnaire and the responses (Table 7).

Table 7. Matrix desirability and optimization level

Rotation	Influencing	Susceptibility
1	%102	%78
2	%100	%100

Table 8. Set of inputs and outputs for level determination

	1: C	2: C	3: C	4: C	5: C	6: C	7: C	8: C	9: C	10: C	11: C	12: C	13: C	14: C	15: C	16: C	17: C	18: C	19: C	20: C
1: C1	65	87	98	115	118	105	109	71	74	82	103	41	81	35	54	74	84	72	65	54
2: C2	66	91	100	119	123	114	112	75	77	85	110	42	86	35	54	81	83	76	71	53
3: C3	78	102	115	136	138	128	128	83	85	94	121	47	93	37	58	87	92	83	78	60
4: C4	21	28	31	39	34	30	37	23	25	26	34	11	25	11	18	25	27	22	16	18
5: C5	35	47	54	64	66	61	60	40	41	45	57	21	44	18	29	43	44	40	37	27
6: C6	72	93	106	125	127	116	118	75	76	84	108	45	83	33	50	78	82	71	71	55
7: C7	32	41	48	56	54	49	54	35	37	40	51	20	41	18	26	37	39	33	28	25
8: C8	30	44	51	60	64	55	57	39	43	49	59	24	49	23	35	45	51	47	41	34
9: C9	28	45	51	60	62	56	56	36	42	50	59	23	49	22	34	45	54	47	41	34
10: C10	30	42	49	54	61	58	51	27	28	42	52	18	38	12	25	39	42	40	40	31
11: C11	33	51	55	66	68	62	60	39	42	48	62	23	51	21	32	45	54	45	41	31
12: C12	50	66	78	97	96	88	88	50	55	67	83	33	63	26	45	65	73	65	58	49
13: C13	23	34	42	45	53	48	42	20	21	37	45	15	38	12	27	34	40	37	35	28
14: C14	53	78	89	108	111	104	98	54	59	78	97	33	75	29	55	76	85	77	68	55
15: C15	42	70	75	83	89	87	79	40	43	64	81	20	58	16	43	57	66	59	55	43
16: C16	72	98	111	133	135	123	125	77	82	95	121	46	96	37	62	91	98	86	79	63
17: C17	80	108	124	148	149	140	138	79	83	102	132	43	98	35	68	99	106	95	84	69
18: C18	70	102	112	131	137	130	123	70	73	93	120	38	89	28	58	88	95	86	84	63
19: C19	64	86	97	119	119	115	109	59	61	78	100	36	75	24	47	76	78	70	73	53
20: C20	84	117	133	157	158	149	146	84	87	107	139	47	105	36	67	102	110	96	92	72

Extent of Direct Mutual Influence

Among Factors Table 9 ranks the identified components based on their direct influence. It should be noted that the degree of influence exerted and received by the driving forces changes depending on the scores they achieve.

Table 9. Extent of Direct Row and Column Influences of the Components

	Component	Row Total	Column Sum
C1	Supply Chain Finance	13	10
C2	Liquidity and Working Capital Management	13	13
C3	Modern Banking Instruments (GAM Bonds, Electronic Bills of Exchange, Letters of Credit)	15	14
C4	Integration of Information Systems between Banks and Petrochemical Companies	4	16
C5	Application of Blockchain for Transparency and Financial Flow Traceability	7	17
C6	Artificial Intelligence and Predictive Cash Flow Analysis	13	15
C7	Transparency and Traceability of Financial Transactions	6	16
C8	Credit and Liquidity Risk Management within the Supply Chain	8	11
C9	Financial Coordination across Upstream, Midstream, and Downstream Segments	8	11
C10	Interactive Digital Platforms and Shared Data Ecosystems	9	12
C11	Cybersecurity and Protection of Financial Data	8	15
C12	Real-time Access to Data on Goods and Financial Flows	12	6
C13	Digital Transformation in the Banking System	7	12
C14	Strategic Collaboration between Banks and Petrochemical Holding Companies	14	5
C15	Standardization of Data Exchange among Supply Chain Participants	11	7
C16	Reducing Reliance on Traditional Financing Methods	15	11
C17	Supply Chain Financial Resilience against Shocks	17	11
C18	Optimizing Financial Resource Allocation Based on Real-world Data	16	9
C19	Facilitating Financial Flows without Physical Fund Transfers	13	9
C20	Banking Support for Value Chain Development and Downstream Industries	18	7
	Total	227	227

Assessment of the Variable Influence-Dependence Map

The distribution and dispersion pattern of variables on the scatter plot indicate the system's stability or instability. In the context of structural/cross-impact analysis using MICMAC software, two types of dispersion are defined: stable systems and unstable systems. In the stable system model, the variables are distributed in an "L" shape; in this model, some variables exhibit high influence while others exhibit high dependence. However, the situation is more complex in unstable systems; here, the forces in question are scattered around the diagonal axis of the plot and often display an intermediate state of influence and dependence, making the identification of key variables difficult. An analysis of the scatter plot for the drivers shaping the future reveals a state of system instability. Most variables are dispersed around the diagonal axis of the plot. With the exception of a few variables that demonstrate high influence within the system, the remaining variables exhibit a roughly similar status relative to one another (Figures 1 and 2).

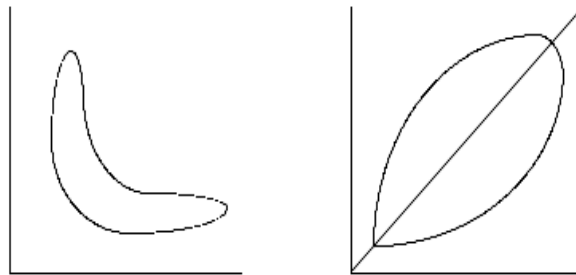
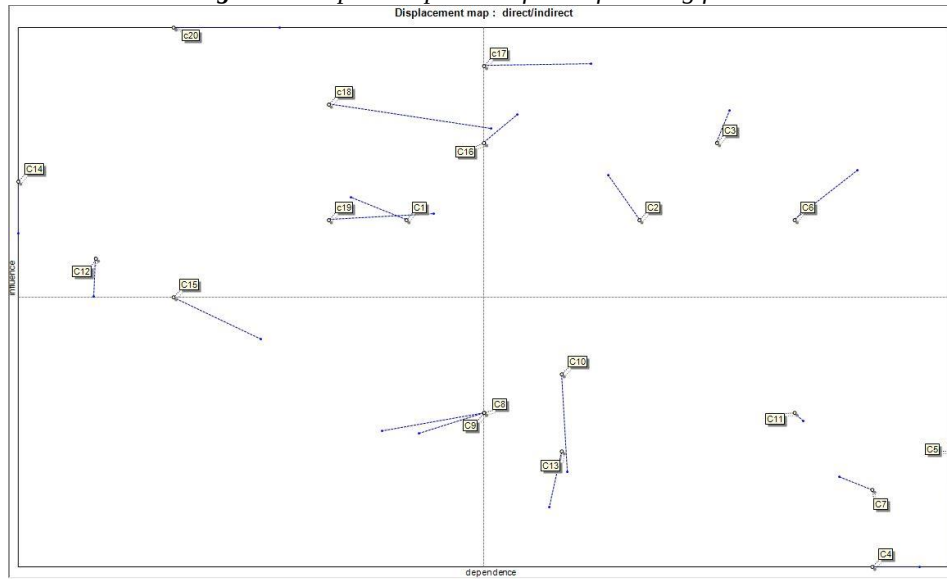
**Figure 2.** Stable system **Figure 1.** Unstable system

Figure 3 illustrates the dispersion pattern of the influencing factors. Overall, this dispersion pattern indicates the state of an unstable system (Figure 3).

Figure 3. Dispersion pattern of the influencing factors

Classification of Influential Factors

Influential (or Determinant) Factors: These factors exert significant influence while being less susceptible to influence themselves; consequently, the system relies heavily on these variables. They appear in the northwest quadrant of the diagram. As the system's changes hinge upon them, these are the most critical components, and the ability to control them is paramount. Furthermore, they are regarded as the system's input variables. Among the 20 factors examined in this study, several—specifically c14 and c20—have been identified as drivers influencing the research model.

"Dual-Nature" (or Ambivalent) Factors: These factors are simultaneously highly influential and highly susceptible to influence. They are located in the northeast quadrant of the diagram. Their nature is characterized by instability, as any action or change affecting them triggers reactions and changes in other factors. This category includes factors c3 and c6.

Dual-nature factors comprise two subsets: risk drivers and goal drivers.

Risk Factors: As shown in the figure, these factors lie above the diagonal line within the northeast quadrant and possess significant potential to become key players in the system. Factors c3, c16, and c17 fall into this category.

Goal Factors: These factors lie below the diagonal line in the northeast quadrant; they represent the system's evolutionary outcomes and potential objectives. Manipulating or altering these factors can drive the system's evolution. Factors c2 and c6 fall into this category.

"Dependent" Factors (or "Outcome" Drivers): These factors are located in the southeast quadrant of the diagram. They exhibit low influence and very high dependence. Consequently, they are highly sensitive to the evolution of influential, dual-nature drivers; they act as output factors. In this study, variables c4, c5, c7, c10, and c13 fall into this category.

Independent or Excluded Factors: These factors possess both low influence and low dependence. Located in the southwestern quadrant of the chart, they appear to have virtually no connection to the system, as they neither halt key factors nor drive their evolution or progress within the system. In this study, variables c8, c9, and c15 fall into this category.

However, within this group, attention should be paid to two specific types of drivers:

"Disconnected" Factors: These factors are located near the origin of the chart's axes. It is inferred that the evolution of these variables is unrelated to the current system dynamics and that they could be removed from the system. No disconnected factors were identified in this study.

"Secondary Leverage" Factors: Although entirely independent, these drivers exert more influence than they receive. Located in the southwestern quadrant of the chart—above the diagonal line—they can serve as reference points for assessment and as benchmarks. In this study, variables c12 and c15 are secondary leverage factors.

"Regulator" Factors: These factors are situated near the chart's center of gravity. They can alternately function as "secondary leverage" factors, "weak targets," or "secondary risk drivers." No regulator drivers were identified in this study.

The figures below provide a graphical representation of the drivers influencing the system. These figures illustrate the direct and indirect effects of the system's drivers on one another. The nature of these influences is categorized into strongest, strong, moderate, weak, and weakest effects.

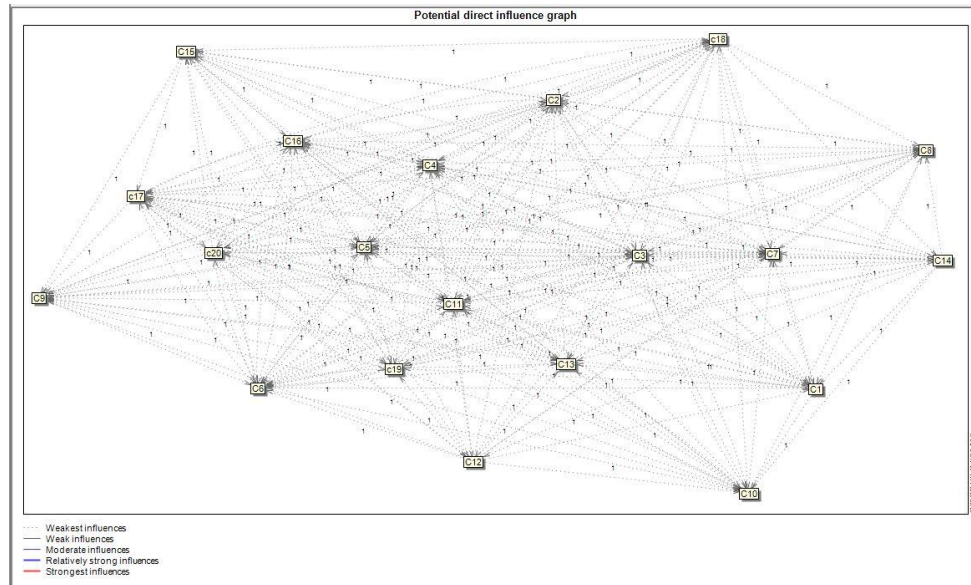


Figure 4. Diagram of direct factor effects (strongest effect)

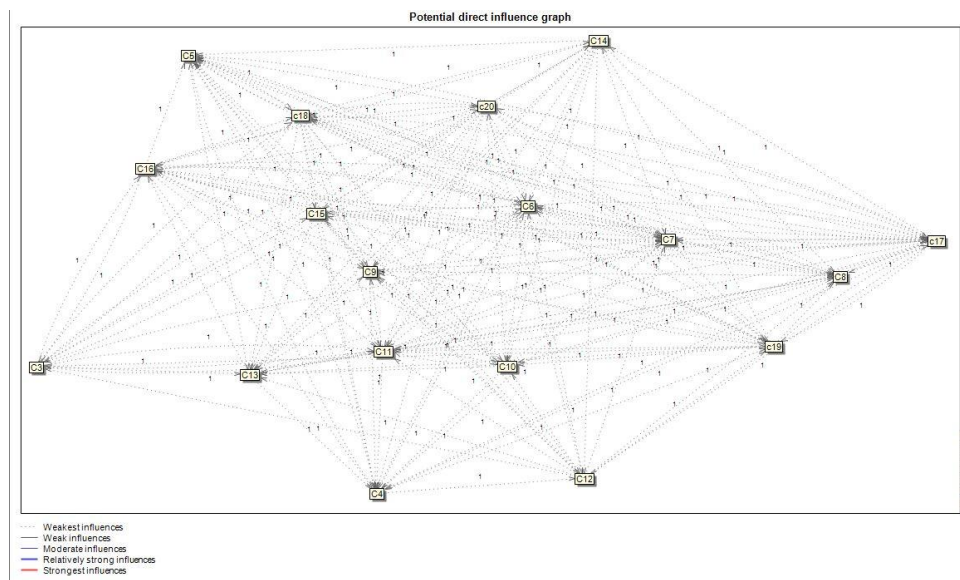


Figure 5. Diagram of direct factor effects (strong impact)

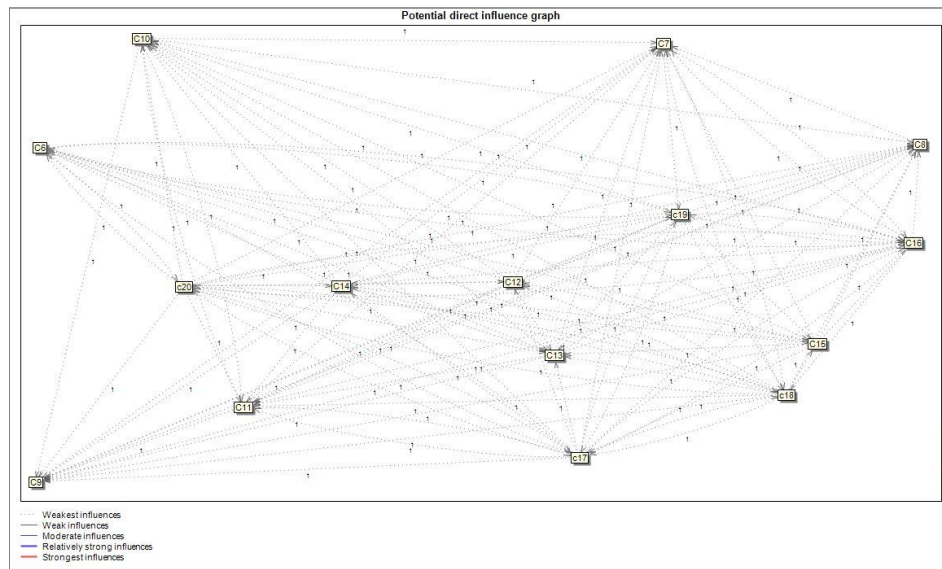


Figure 6. Diagram of direct factor effects (median effect)

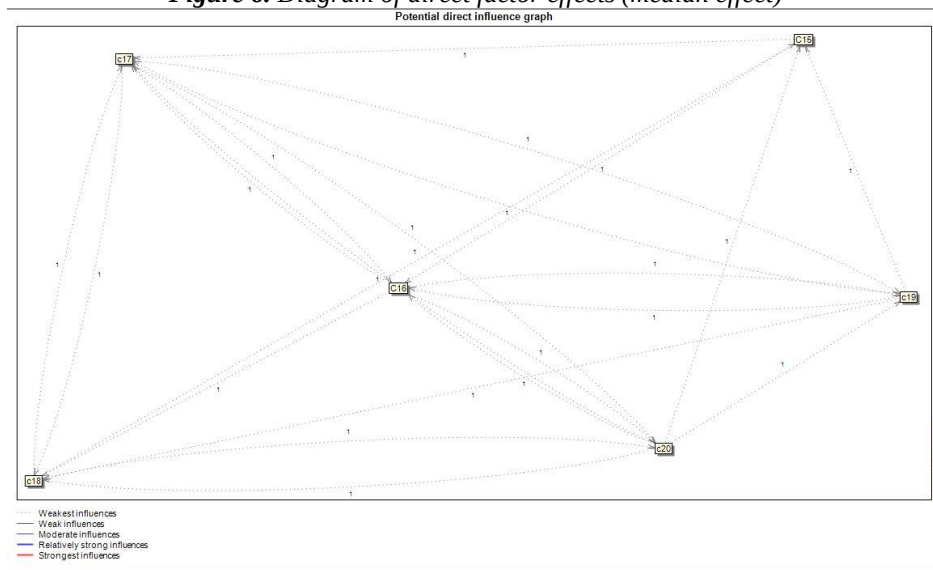


Figure 7. Diagram of direct factor impacts (weak impacts)

Among the 20 drivers examined in this study, five key influential components were selected (c3, c16, c17, c18, c20). These components are considered the most influential and pivotal drivers of the system (Table 10).

Table 10. Magnitude of direct impacts of factors on one another

Rank	Label	Direct Influence	Label	Direct dependence	Label	Indirect Influence	Label	Indirect dependence
1	c20	792	C5	748	c20	795	C5	747
2	c17	748	C4	704	c17	754	C4	729
3	c18	704	C7	704	C3	702	C6	692
4	C3	660	C6	660	C16	697	C7	682
5	C16	660	C11	660	c18	682	C11	660
6	C14	616	C3	616	C6	635	C3	616
7	C1	572	C2	572	C2	629	C2	544
8	C2	572	C10	528	C1	604	c17	534
9	C6	572	C13	528	c19	586	C10	520
10	c19	572	C8	484	C14	564	C13	509
11	C12	528	C9	484	C12	493	C16	490
12	C15	484	C16	484	C15	445	c18	475
13	C10	396	c17	484	C11	354	c19	440
14	C8	352	C1	440	C8	342	C9	432
15	C9	352	c18	396	C9	340	C8	410
16	C11	352	c19	396	C5	332	C1	391
17	C5	308	C15	308	C10	296	c20	349
18	C13	308	c20	308	C7	291	C15	338
19	C7	264	C12	264	C13	257	C12	238
20	C4	176	C14	220	C4	190	C14	193

Rank	Label	Potential Direct Influence	Label	Potential Direct Influence	Label	Potential Direct Influence	Label	Potential Direct Influence
1	C20	792	C5	748	C20	795	C5	747
2	C17	748	C4	704	C17	754	C4	729
3	C18	704	C7	704	C3	702	C6	692
4	C3	660	C6	660	C16	697	C7	682
5	C16	660	C11	660	C18	682	C11	660
6	C14	616	C3	616	C6	635	C3	616
7	C1	572	C2	572	C2	629	C2	544
8	C2	572	C10	528	C1	604	C17	534
9	C6	572	C13	528	C19	586	C10	520
10	c19	572	C8	484	C14	564	C13	509
11	C12	528	C9	484	C12	493	C16	490
12	C15	484	C16	484	C15	445	C18	475
13	C10	396	C17	484	C11	354	C19	440
14	C8	352	C1	440	C8	342	C9	432
15	C9	352	C18	396	C9	340	C8	410
16	C11	352	C19	396	C5	332	C1	391
17	C5	308	C15	308	C10	296	C20	349
18	C13	308	C20	308	C7	291	C15	338
19	C7	264	C12	264	C13	257	C12	238
20	C4	176	C14	220	C4	190	C14	193

To assess validity and reliability in the MICMAC technique, the validity of the findings is established through the purposive selection of experts familiar with the research topic, the precise and transparent identification of variables based on theoretical foundations and previous research, and the verification and review of the variables and their interrelationships by specialists. Furthermore, to enhance the reliability of the analysis, the cross-impact matrix is systematically constructed using a predefined scale to assess the intensity of influence among variables. Experts are also asked to evaluate the direct relationships between variables based on their operational definitions and the conceptual framework of the study. Where feasible, the matrices are reassessed after a specified time interval, or the evaluations provided by multiple experts are compared to determine the degree of stability and agreement in identifying relationships. Finally, confidence in the robustness of the findings is strengthened by examining matrix consistency, analyzing direct and indirect influences, and comparing the results of repeated analyses when additional data are available. It should be noted that the MICMAC technique does not, in itself, provide a standardized coefficient for measuring validity or reliability. Therefore, its validity and reliability should be assessed and reported based on documented evidence obtained from expert judgments, the transparency of the scoring process, the degree of agreement among evaluators, and the stability of the analytical results.

Discussion

The structural analysis derived from the MICMAC methodology demonstrates that the analyzed petrochemical supply chain financial ecosystem operates in a state of structural instability. Rather than exhibiting the conventional L-shaped dispersion characteristic of mature, stable systems, the evaluated variables congregate prominently along the diagonal bisector of the direct and indirect influence-dependence plane. This topological distribution reveals an intricate web of bilateral feedback loops, non-linear interdependencies, and transitive systemic pressures that govern financial flows under digital transformation and interactive metaverse environments. In such dynamic and sensitive ecosystems, targeted interventions in primary driving nodes propagate multi-tier ripple effects across the entire network. Consequently, isolating and governing core system drivers is essential for establishing an adaptive strategic digital banking framework.

Based on cumulative direct and indirect hierarchical rankings, five primary variables emerged as the definitive driving forces of the system: banking support for value chain expansion and downstream industries (C20) (Qu et al., 2024), supply chain financial resilience against exogenous shocks (C17), real-time data-driven financial resource allocation (C18), deployment of novel digital banking instruments (C3), and decoupling from legacy, collateral-heavy debt financing (C16) (Yang et al., 2026). The positioning of C20 at the apex of systemic influence corroborates the paradigm shift required in commercial banking: institutions must transcend passive, transactional liquidity underwriting and evolve into strategic orchestrators that finance downstream polymer diversification and close structural value gaps (Pan et al., 2025). Furthermore, the structural prominence of financial resilience (C17) alongside real-time data allocation (C18) highlights that within macroeconomic volatility and international sanctions, data-driven liquidity modeling serves as an indispensable prerequisite for maintaining macro-financial continuity.

Crucially, linkage and bifacial variables—namely novel digital banking instruments (C3), artificial intelligence and predictive analytics (C6), and mitigating reliance on conventional financing (C16)—constitute the volatile pivot points of the framework (Babaei et al., 2025). Characterized by high driving power paired with high dependence, any regulatory or technological perturbation within these components can either accelerate systemic efficiency or amplify structural instability. In contrast, variables such as cross-enterprise information system integration (C4), blockchain application (C5), and transaction transparency (C7) emerge predominantly as dependent output nodes (Jain et al., 2024). This structural finding delivers a critical insight for metaverse and Web3 adoption: digital technologies and interactive virtual environments do not function as autonomous systemic panaceas; rather, their efficacy depends strictly on the strategic maturity of banking mechanisms and institutional liquidity architecture.

Synthesizing these empirical findings, the strategic framework demands that banking institutions transition from traditional credit lenders into intelligent ecosystem orchestrators and value-chain facilitators. By leveraging real-time data feeds, programmable digital instruments, and AI-driven liquidity simulations within collaborative virtual environments, the banking sector can construct a resilient, self-synchronizing financial value chain. This structural transition offers petrochemical holding corporations, banking syndicates, and financial policymakers a clear strategic roadmap to de-risk capital flows, insulate downstream petrochemical operations, and accelerate sustainable digital transformation.

Conclusion

The structural analysis of Iran's petrochemical supply chain financial system reveals a state of systemic instability, characterized by complex feedback loops and critical dependencies on five primary drivers: banking support for value chain expansion (C20C_{20}C20), financial resilience against exogenous shocks (C17C_{17}C17), real-time data-driven resource allocation (C18C_{18}C18), deployment of novel digital instruments (C3C_{3}C3), and decoupling from legacy debt-financing (C16C_{16}C16). The findings underscore that traditional, siloed financing approaches are not only insufficient but exacerbate structural risks in the current volatile economic environment.

To transcend this instability, a fundamental paradigm shift is required. Banking institutions must evolve from passive credit underwriters into intelligent, proactive orchestrators of the industrial financial ecosystem. In the context of the emerging industrial metaverse and interactive digital environments, the banking sector's role must be redefined to provide high-frequency, data-informed liquidity orchestration. Success in this strategic roadmap necessitates the transition from conventional lending to programmable, tokenized, and automated financial settlements. Failure to prioritize these drivers and integrate banking functions into the digital-twin architectures of petrochemical holding companies will leave the industry vulnerable to systemic shocks, whereas a coordinated, technological-led

transformation provides the only viable path to long-term resilience and operational competitiveness.

Strategic Recommendations

To operationalize this strategic framework, the following recommendations are proposed for stakeholders, policymakers, and financial institutions:

1. Institutional Reconfiguration of Banking Roles

Commercial banks should establish specialized divisions for “Digital Supply Chain Finance” (DSCF). These units must shift the focus of capital allocation from generic credit facilities toward strategic projects that simultaneously foster downstream polymer diversification and strengthen financial resilience. Banks are encouraged to adopt a “banking-as-a-service” (BaaS) approach, integrating their liquidity infrastructure directly into the digital ecosystems of petrochemical supply chains.

2. Development of Unified Data Interoperability Platforms

It is imperative for banks and petrochemical holding groups to co-develop collaborative, real-time data platforms. These platforms should serve as the “single source of truth,” providing granular visibility into material and financial flows. This level of interoperability is the prerequisite for deploying advanced technological layers, such as real-time liquidity simulations and AI-driven resource optimization.

3. Implementation of Programmable Financial Instruments

Priority must be given to the adoption of advanced digital banking instruments, including smart contracts, electronic trade bills, and chain-based letters of credit. By transitioning to programmable money architectures, the system can facilitate automated, cross-organizational settlements that bypass the logistical and bureaucratic frictions of physical document exchange, thereby accelerating the velocity of capital circulation.

4. Predictive Risk Governance and Resilience

Both banking syndicates and petrochemical conglomerates must design joint resilience programs incorporating AI-driven predictive analytics. These mechanisms should be capable of anticipating disruptions—such as feed shortages, currency fluctuations, or sanction-induced delays—and triggering automated risk-mitigation protocols, such as dynamic reserve funds or blockchain-based credit insurance, before structural instability occurs.

5. Standardization as a National Strategic Initiative

Standardizing data exchange protocols between banks, petrochemical entities, and commodity exchanges should be elevated to a national-level project. Establishing these standards is crucial for unlocking the potential of decentralized technologies (e.g., blockchain for provenance and transparency) and ensuring that financial transactions remain traceable, auditable, and immutable within the immersive digital environments of the industrial metaverse.

6. Regulatory Facilitation and Incentivization

Regulatory bodies, including the Central Bank and the Ministry of Petroleum, should introduce agile, pro-innovation regulations that incentivize cross-industry collaboration. By providing specific policy frameworks and financial incentives for joint digital transformation projects, regulators can actively de-risk the transition from the current fragmented, unstable state toward a cohesive, technology-enabled, and future-proof financial ecosystem.

Declaration of Competing Interest

The author declares that he has no competing financial interests or known personal relationships that would influence the report presented in this article.

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