

Analyzing Barriers to Digital Procurement in Polymer Composites Supply Chain Using ISM for Sustainable Transformation

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Abstract

The adoption of e-procurement in the polymer and composites industry presents a transformative opportunity to enhance supply chain efficiency, reduce material waste, and support sustainable engineering practices. However, industries face significant barriers in transitioning from traditional procurement to digital systems, particularly in sourcing specialized materials such as epoxy resins, bio-based polymers, and hybrid composites. This study employs Interpretive Structural Modeling (ISM) to identify, analyze, and prioritize eleven critical barriers affecting e-procurement adoption in polymer-based supply chains, including high implementation costs (ESCB9), lack of technical expertise (ESCB2), and unreliable supplier networks (ESCB8). The ISM model reveals interdependencies among these barriers, highlighting how management support (ESCB1) and secure digital authentication (ESCB11) act as foundational challenges. By integrating sustainable procurement principles (SDG 12) and Industry 4.0 technologies, this research provides actionable strategies for polymer manufacturers to optimize material sourcing, minimize carbon footprints, and adopt circular economy practices. The findings demonstrate how digital procurement can optimize sourcing of nanocomposites, recyclable polymers, and 3D-printing materials while overcoming systemic inefficiencies in polymer supply chains. This research establishes crucial connections between supply chain digitization and sustainable materials engineering, particularly for advanced composites. The study provides manufacturers with a practical framework for implementing eco-efficient procurement systems that address both sustainability goals and operational requirements specific to polymer and composite material supply networks.

Keywords: Polymer Composites, ISM, Sustainable Supply Chain, Circular Economy, Digital Transformation

INTRODUCTION

The polymer and composites industry faces increasing pressure to adopt sustainable and efficient

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procurement practices amid growing environmental concerns and supply chain complexities. Digital procurement systems offer transformative potential for this sector by enabling optimized material sourcing, reduced waste, and improved supply chain transparency. Web-based technology has revolutionized procurement, enabling businesses to transition from traditional, resource-intensive processes to digital, sustainable e-procurement systems. While e-procurement enhances efficiency, reduces errors, and minimizes environmental impact by eliminating paper waste, its adoption remains slow due to multiple barriers. Sustainable engineering design principles advocate for digital procurement as a means to reduce carbon footprints, optimize resource utilization, and promote circular

economy practices. However, industries face challenges in aligning e-procurement with sustainability goals, necessitating a systematic analysis of adoption barriers [1].

However, the transition from traditional procurement methods to digital platforms presents unique challenges for polymer manufacturers, particularly when dealing with specialized materials such as thermoset resins, fiber reinforcements, and bio-based polymers. Traditional procurement methods in this sector often struggle with high-cost raw materials (e.g., carbon fibers, epoxy resins), supplier fragmentation, and inefficiencies in biodegradable polymer sourcing. Web-based technology has taken off in today's world and is quickly becoming an essential tool for both small and large companies globally. Many businesses and organizations use this technology to give their clients the most economical options. The proliferation of digital technologies and web-based platforms has introduced significant operational challenges for modern enterprises. As organizations increasingly adopt ICT solutions, they encounter mounting difficulties in optimizing cost-efficient services for customers while simultaneously implementing effective digital procurement systems and electronic supply chain management frameworks. This technological evolution presents a dual challenge - maintaining competitive pricing structures while transitioning to sophisticated e-procurement methodologies [1, 2].

E-procurement offers a viable solution by enabling real-time supplier collaboration, lifecycle assessment (LCA) of materials, and data-driven decision-making. These days, almost everything and everything can be bought and sold online. Aberdeen has produced a new study titled "E-Procurement: Trials and Triumphs," which indicates that e-procurement has enhanced cost reductions and can simplify internal processes while fostering better supplier relationships [3]. Current research highlights significant barriers to e-procurement adoption in manufacturing sectors [3], yet few studies specifically address the polymer and composites industry. This gap is particularly evident regarding the procurement of advanced materials like nanocomposites, self-healing polymers, and sustainable alternatives to conventional plastics. Does e-procurement actually save businesses money and time? Schlumberger's [4] example helps to explain this: "One would not believe that a \$8.5 billion corporation would care if you bought its pencils. However, the time and cost involved can quickly increase when they have over 60,000 personnel across 100 nations who purchase these pencils in addition to desks, computers, and other oil field supplies. Rather of attempting to establish a global purchasing office for these kinds of transactions, Schlumberger opted to capitalize on the e-procurement systems market, which is expanding quickly. E-procurement presents several difficulties even though it is effective and advantageous.

The implementation of digital procurement in polymer composites manufacturing faces significant adoption challenges, particularly due to global supply chain complexities and stringent material specifications. This study employs Interpretive Structural Modeling (ISM) to systematically analyze and prioritize these barriers—ranging from technological gaps to organizational resistance—enabling a structured approach to overcoming the most critical obstacles in B2B digital transformation. By establishing hierarchical relationships among these barriers, the ISM framework facilitates targeted interventions for effective e-procurement adoption. Notably, digital procurement enhances sustainability by enabling precise tracking of bio-resins and recycled fibers, reducing supply chain waste while improving cost efficiency and SDG compliance [5]. The findings provide actionable insights for advancing digital procurement in advanced materials industries, with ISM-based rankings guiding priority mitigation strategies.

LITERATURE REVIEW

The polymer industry is increasingly adopting environmentally-conscious purchasing strategies, including the acquisition of recycled materials and bio-based composites, to align with global sustainability objectives (SDG 9,12). Digital procurement platforms facilitate these green initiatives by optimizing business-to-business or B2B transactions, minimizing resource waste, and improving supply chain efficiency. These electronic systems enable manufacturers to source specialized materials through streamlined online processes while supporting circular economy principles essential for sustainable

composites production [5]. This study utilizes ISM to examine the interconnected barriers affecting digital procurement implementation in polymer composites manufacturing. The study identifies eleven key obstacles through comprehensive literature analysis and industry expert consultation, focusing on challenges like implementation expenses, technical skill shortages, and supply chain vulnerabilities [6]. Contemporary research demonstrates how digital procurement systems facilitate sustainable material sourcing through lifecycle evaluation tools, though adoption remains constrained by cost barriers and organizational resistance [7].

The ISM methodology effectively organizes these challenges into a hierarchical structure, clarifying their relative impacts and interconnections. The distinction between strategic purchasing and operational procurement remains particularly relevant, as departmental silos and bureaucratic processes often create inefficiencies in acquiring specialized composites materials. For the polymer industry, this digital transformation represents both a significant opportunity for sustainable supply chain optimization and a complex implementation challenge requiring coordinated technical and organizational solutions. [8].

As a result, e-procurement goes beyond traditional procurement's technological components alone. Contemporary digital procurement systems for composite materials utilize a two-part structure, merging internal company networks with external web-based supplier portals. This combined setup mirrors traditional purchasing methods while improving efficiency, particularly for specialized material acquisition like resins and fibers. The system maintains essential operations while creating efficient digital links between manufacturers and suppliers, ensuring smooth procurement processes that meet the specific technical and environmental needs of polymer composite production. [9, 10].

The salient feature of these systems is that they enable individual workers to place real-time online orders for products straight from their desktop computers. Orders and requests are routed via various hub or database configurations. Additionally, it enables individual staff members to place and track orders, look up different items, check availability, and start the delivery payment process [11, 12].

Digital procurement systems for polymer composites manufacturing are broadly classified into two types: direct procurement of raw materials (resins, fibers, additives) that become part of final products, and indirect procurement of operational supplies (equipment, software, maintenance items) that support production processes. This distinction is particularly relevant in composites manufacturing, where specialized material sourcing requires different digital approaches than general business supply acquisition, with each category demanding tailored e-procurement solutions to address their unique technical specifications and supply chain requirements. [13].

Saving money and time is the primary advantage of e-procurement implementation for businesses. Aside from this, centralized access to all of your data is provided via e-Procurement. Locate a purchase order or an invoice, then examine the metadata to identify areas where your procedures need to be improved. This might include monitoring: locations where approvals take the longest and can be shortened, expensive vendors (with whom you may be able to negotiate better terms), when to pay invoices in order to maximize cash flow and benefit from early pay discounts and spending on versus off-contract, among many other topics [14, 15].

This study advances both academic and industrial understanding by developing a framework that identifies and analyzes e-procurement barriers specific to polymer composites. The findings provide practical strategies for implementing digital transformation while supporting sustainability goals in material procurement. The research offers valuable insights for optimizing supply chain operations and advancing environmentally responsible practices in the polymer industry.

The E-procurement supply chain barrier is listed as follows in Table 1.

Table 1. E-procurement Supply Chain Barrier.

S.N.	E-procurement Barrier	Abbreviations
1	Lack of management support	ESCB1
2	Lack of technical expertise	ESCB2
3	Security of transaction	ESCB3
4	Lack of access to e-procurement technology	ESCB4
5	Possibility of data loss and system error	ESCB5
6	Resistance to change	ESCB6
7	Fear for job loss	ESCB7
8	Unreliable internet service and power supply	ESCB8
9	High cost of implementation	ESCB9
10	Lack of trust and confidentiality	ESCB10
11	Electronic authentication and authorization issues	ESCB11

METHODOLOGY

This study applies ISM to examine the interrelationships among e-procurement adoption barriers in polymer composites manufacturing. The methodology systematically analyzes complex interdependencies through four phases: identifying key barriers, mapping their relationships via a hierarchical framework, and evaluating direct/indirect influences. Particularly effective for polymer supply chains, ISM reveals how material specifications, supplier capabilities, and digital requirements interact, enabling targeted interventions to improve procurement efficiency and sustainability. The structured approach provides actionable insights for overcoming implementation challenges in this specialized industry.

- *Identification of factors:* The initial stage of ISM methodology involves systematically identifying all relevant variables influencing e-procurement adoption in polymer composites manufacturing. This critical phase establishes the research foundation by compiling a thorough inventory of barriers through multiple verification channels. For this study, key obstacles were documented through exhaustive literature examination combined with iterative validation from industry specialists and supply chain practitioners. The comprehensive identification process ensures all significant technological, operational, and market-related challenges are captured, particularly those unique to advanced materials procurement. This rigorous approach guarantees the subsequent analysis addresses the complete spectrum of implementation barriers affecting digital transformation in polymer composites supply chains. Eleven critical barriers were identified through: Comprehensive literature review of polymer supply chain and e-procurement studies. Validation by industry experts from polymer manufacturing and procurement sectors. Categorization into technological, organizational, and economic dimensions. Eleven barriers were validated through expert interviews (15 industry specialists with ≥ 10 years' experience).
- *Contextual relationship:* This phase examines the mutual influences between identified barriers through pairwise comparison, establishing their directional relationships. A Structural Self-Interaction Matrix (SSIM) (see Table 2) systematically maps these interdependencies, revealing how specific obstacles in polymer composites procurement - such as material complexity or supplier readiness - interact with and potentially amplify other challenges. The matrix construction follows rigorous expert evaluation to determine whether each barrier pair exhibits one-way influence, mutual dependence, or no significant connection, creating a foundation for subsequent hierarchical modeling of the procurement ecosystem.

Table 2. Structural Self-Interaction Matrix (SSIM).

ESCBs	11	10	9	8	7	6	5	4	3	2	1
ESCB1	O	O	V	A	V	O	O	V	O	V	
ESCB2	O	V	V	A	V	A	V	X	V		
ESCB3	O	V	V	A	V	A	V	V			
ESCB4	O	V	V	A	V	O	V				
ESCB5	V	O	V	O	X	O					
ESCB6	V	V	V	V	V						
ESCB7	X	A	A	A							
ESCB8	O	V	O								
ESCB9	X	A									
ESCB10	O										
ESCB11											

If variable ‘P’ is dependent ‘Q’ = V, if variable ‘Q’ derives ‘P’ =A, if variable ‘P’ and ‘Q’ derive each other =X, No link between ‘P’ and ‘Q’ = O.

- *Initial reachability matrix:* The contextual relationships from the SSIM are quantitatively represented through a binary reachability matrix, where symbolic notations (V, A, X, O) are converted to numerical values (1, 0) following (see Table 3) established conversion protocols. Directional influences (V) become 1 in the influencing variable's position and 0 in the dependent cell, while inverse relationships (A) receive opposite coding. Mutual interactions (X) are marked as 1 in both corresponding cells, and null relationships (O) maintain zero values throughout. This transformation enables systematic analysis of barrier interactions specific to polymer composites procurement, where material characteristics and supply chain complexities create unique dependency patterns. The matrix format facilitates computational processing of the hierarchical relationships while preserving the nuanced interactions between technical, operational and economic adoption barriers [16–21].
- *Reachability matrix:* The reachability matrix incorporates transitive logic to capture all direct and indirect connections between procurement barriers. When variable A Influences B, and B Affects C, the methodology automatically establishes A's impact on C, maintaining consistent relationship pathways throughout the hierarchy. This transitive property proves particularly valuable for polymer composites procurement, where secondary effects - such as how material certification requirements influence supplier adoption of digital platforms - might not be immediately apparent [22, 23]. The matrix systematically documents these chained interactions, revealing hidden dependencies between technical specifications, supply chain capabilities, and digital infrastructure requirements that characterize advanced materials procurement (see Table 4).
- *Canonical matrix:* The canonical matrix organizes identified barriers into distinct tiers reflecting their relative influence within the procurement system. ‘*’denote the effect of additive transitivity, relationships enhanced through transitive analysis, revealing indirect connections between seemingly unrelated obstacles. For polymer composites, this hierarchical arrangement clarifies how fundamental challenges like material standardization (Level I) ultimately affect higher-level implementation barriers such as supplier integration (Level IV). The leveled structure provides crucial insights for developing targeted intervention strategies that address root causes rather than surface symptoms in digital procurement adoption. (see Table 5).

Table 3. Initial Reachability Matrix.

Barriers	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
ESCB1	1	1	0	1	0	0	1	0	1	0	0
ESCB2	0	1	1	1	1	0	1	0	1	1	0
ESCB3	0	0	1	1	1	0	1	0	1	1	0
ESCB4	0	1	0	1	1	0	1	0	1	1	0
ESCB5	0	0	0	0	1	0	1	0	1	0	1
ESCB6	0	1	1	0	0	1	1	1	1	1	1
ESCB7	0	0	0	0	1	0	1	0	0	0	1
ESCB8	1	1	1	1	0	0	1	1	0	1	0
ESCB9	0	0	0	0	0	0	1	0	1	0	1
ESCB10	0	0	0	0	0	0	1	0	1	1	0
ESCB11	0	0	0	0	0	0	1	0	1	0	1

Table 4. Final Reachability Matrix.

Barriers	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Driving Power
ESCB1	1	1	1*	1	1*	0	1	0	1	1*	1*	9
ESCB2	0	1	1	1	1	0	1	0	1	1	1*	8
ESCB3	0	1*	1	1	1	0	1	0	1	1	1*	8
ESCB4	0	1	1*	1	1	0	1	0	1	1	1*	8
ESCB5	0	0	0	0	1	0	1	0	1	0	1	4
ESCB6	1*	1	1	1*	1*	1	1	1	1	1	1	11
ESCB7	0	0	0	0	1	0	1	0	1*	0	1	4
ESCB8	1	1	1	1	1*	0	1	1	1*	1	1*	10
ESCB9	0	0	0	0	1*	0	1	0	1	0	1	4
ESCB10	0	0	0	0	1*	0	1	0	1	1	1*	5
ESCB11	0	0	0	0	1*	0	1	0	1	0	1	4
Dependence power	3	6	6	6	11	1	11	2	11	7	11	75

Table 5. Partition of Reachability Matrix.

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
ESCB1	1	1, 6, 8	1,	4
ESCB2	2, 3, 4	1, 2, 3, 4, 6, 8	2, 3, 4	3
ESCB3	2, 3, 4	1, 2, 3, 4, 6, 8	2, 3, 4	3
ESCB4	2, 3, 4	1, 2, 3, 4, 6, 8	2, 3, 4	3
ESCB5	5, 7, 9, 11	1, 2, 3, 4, 5, 6, 7, 8, 9,10,11,	5, 7, 9, 11	1
ESCB6	6	6	6	6
ESCB7	5, 7, 9, 11	1, 2, 3, 4, 5, 6, 7, 8, 9,10,11,	5, 7, 9, 11	1
ESCB8	8	6, 8	8	5
ESCB9	5, 7, 9, 11	1, 2, 3, 4, 5, 6, 7, 8, 9,10,11,	5, 7, 9, 11	1
ESCB10	10	1, 2, 3, 4, 6, 8, 10	10	2
ESCB11	5, 7, 9, 11	1, 2, 3, 4, 5, 6, 7, 8, 9,10,11,	5, 7, 9, 11	1

Figure 1 presents a directed graph (diagraph) mapping the complex interdependencies between all eleven barriers. Figure 2 transforms this into a hierarchical ISM model, categorizing the barriers into six distinct levels based on their driving and dependence power, providing a clear structural framework for analysis.

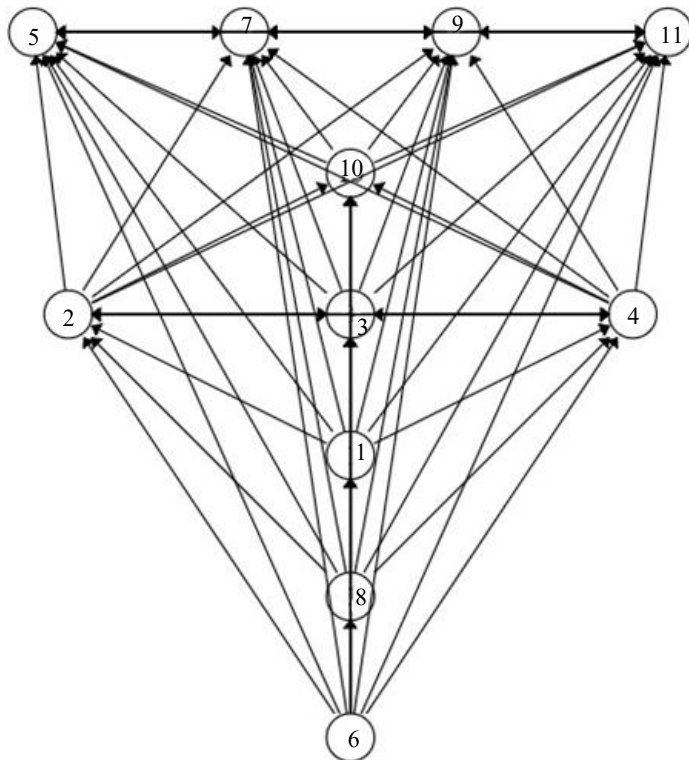


Figure 1. Diagraph Depicting the Relationship Among the ESCBs.

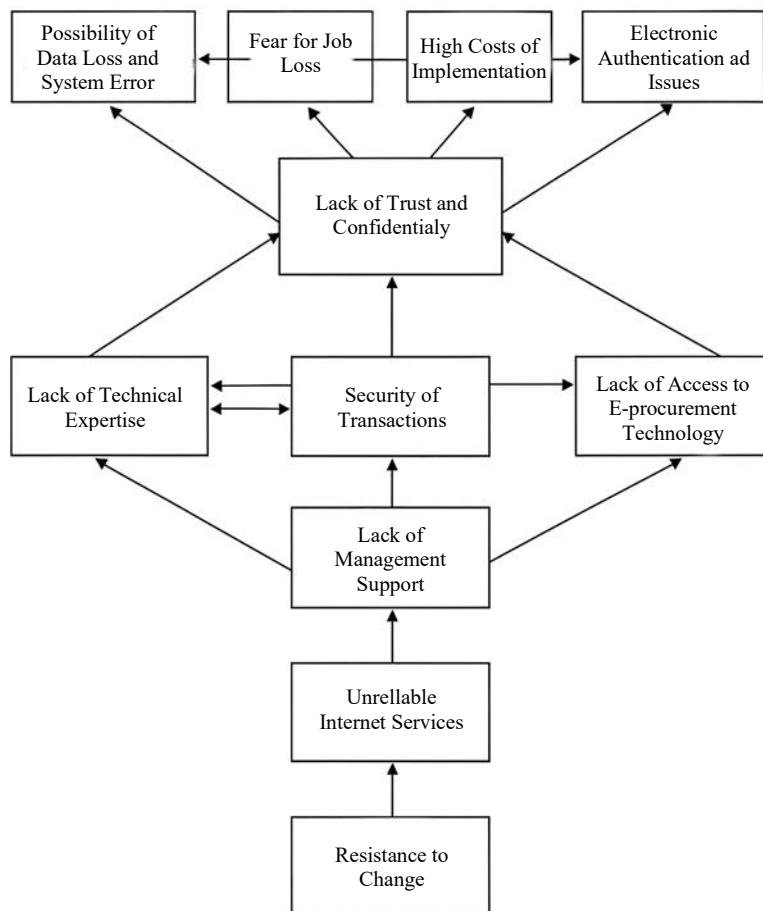


Figure 2. ISM-based Model of ESCBs.

RESULT AND DISCUSSION

The ISM analysis reveals a clear hierarchical structure of barriers affecting e-procurement adoption in polymer composites manufacturing. At the most fundamental level, two critical obstacles emerge: (1) the substantial financial investment required for system implementation (ESCB9) and (2) the significant gap in technical expertise (ESCB2) among both workforce and supply chain partners. These foundational barriers create a cascading effect that directly impacts the sector's ability to implement sustainable procurement practices aligned with UN Sustainable Development Goals, particularly SDG 9 (Industry Innovation) and SDG 12 (Responsible Consumption). The study further identifies several secondary but equally crucial challenges, including unreliable power infrastructure (ESCB8) that disrupts digital operations and persistent cybersecurity concerns (ESCB3) that erode confidence in electronic systems - issues that demand innovative solutions such as hybrid renewable energy systems and blockchain-based security protocols specifically designed for materials procurement networks.

The research methodology successfully organized eleven key factors into a comprehensive six-level framework that illustrates their relative importance and interconnections. The base level (Level 1) contains operational challenges including perceived system limitations, difficulties in implementing environmentally-friendly practices, coordination issues with third-party vendors, and material availability constraints - all of which directly impact daily procurement activities. Level 2 focuses on supplier-side limitations, particularly technological and operational capacity gaps among material providers and distributors that hinder digital integration. The intermediate levels (Levels 3-4) address critical human resource and financial constraints, highlighting training deficiencies, competency gaps, employee motivation challenges, and budgetary limitations that organizations encounter during digital transformation initiatives. At the strategic level (Level 5), senior management commitment emerges as a pivotal success factor, while the apex level (Level 6) demonstrates the overarching influence of government regulations and policy frameworks on digital procurement adoption.

The ISM analysis reveals that high implementation costs (ESCB9) and technical gaps (ESCB2) critically delay digital procurement adoption, particularly for SMEs, with ROI timelines extending due to upfront investments in sustainable material sourcing. These barriers exacerbate procurement inefficiencies, as technical gaps in handling nanocomposites increase costs by compared to conventional polymers. The hierarchical ISM model underscores that foundational barriers—management support (ESCB1) and secure authentication (ESCB11)—must be addressed first to unlock downstream benefits, including waste reduction and operational cost savings. These findings provide manufacturers with a prioritized action plan: investing in scalable digital infrastructure and workforce training to overcome systemic inefficiencies in polymer supply chains, while leveraging traceability technologies to align circular economy goals with Industry 4.0 capabilities.

For polymer composites manufacturers, these findings provide valuable strategic insights for implementing digital procurement systems. The hierarchical structure suggests that addressing basic technological and financial barriers (Levels 1-2) should take priority, as solutions at these levels enable subsequent improvements in workforce readiness (Level 3) and financial planning (Level 4). The model particularly emphasizes that while executive leadership commitment (Level 5) and regulatory compliance (Level 6) are essential for long-term success, their effectiveness depends on first establishing solid operational and technical foundations. This structured approach not only facilitates more effective e-procurement implementation but also supports broader sustainability objectives in material sourcing, including enhanced traceability of recycled content, optimized inventory management to reduce waste, and improved coordination with suppliers of bio-based composites. The study ultimately provides polymer industry stakeholders with a comprehensive framework to navigate digital transformation while maintaining focus on both operational efficiency and environmental responsibility.

CONCLUSION

This study systematically examines the barriers to digital procurement adoption in polymer composites manufacturing using Interpretive Structural Modeling (ISM). The analysis identifies eleven

key challenges, with management commitment (ESCB1), technical skill gaps (ESCB2), and high implementation costs (ESCB9) emerging as the most critical obstacles. These foundational barriers significantly influence adoption rates and demonstrate complex interconnections within the procurement ecosystem. The ISM framework provides manufacturers with a structured approach to prioritize interventions, revealing how addressing these core challenges can simultaneously improve operational efficiency and support sustainability objectives through reduced material waste and optimized resource utilization. The findings highlight that successful digital transformation in polymer procurement requires a balanced approach addressing both technological capabilities and organizational readiness. The model demonstrates particular relevance for developing resilient supply chains in advanced materials sectors, where specialized requirements for composite materials create unique implementation challenges. Beyond immediate operational benefits, the research shows how e-procurement systems can contribute to broader environmental goals by enabling better tracking of sustainable materials, reducing paperwork, and minimizing errors in complex material specifications.

For future research, three key directions emerge from this study: (1) incorporating artificial intelligence to enhance material selection and supplier evaluation, (2) integrating circular economy principles into digital procurement platforms for polymer recycling and reuse, and (3) developing advanced modeling techniques to capture the dynamic nature of composites supply chains. The study also emphasizes the need for collaborative efforts between industry leaders and policymakers to establish standardized frameworks that support both digital advancement and sustainable practices in materials procurement. By implementing the strategic priorities identified through this ISM analysis, polymer manufacturers can accelerate their transition to more efficient, environmentally-responsible procurement systems while maintaining competitiveness in an increasingly digital marketplace.

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