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# A Combined Soft Systems and Interpretive Structural Modeling Approach to Enhancing Financial and Commercial Resilience

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**ABSTRACT:** This research examines the challenge of financial resilience in the wood fiber industry, where climate variability, geopolitical uncertainty, and regulatory demands affect cash flow and operational stability. The objective is to identify and prioritize the structural drivers of financial leakage within the bio industrial supply chain, moving beyond traditional linear cost analysis. The study uses a descriptive diagnostic approach with a mixed method design that integrates Soft Systems Methodology and Interpretive Structural Modelling. Data was gathered through in-depth interviews with three senior informants with strategic P&L responsibility at the Riau Mill Complex in Indonesia, representing a specialized finance related persona cluster. The analysis shows a hierarchical structure in which Global Uncertainty and Compliance Burden function as independent drivers, while Escalating Operation Costs and Delays appear as dependent outcomes rather than root causes. The findings indicate that internal Agency Costs and Human Capital Deficits mediate the link between external pressures and financial symptoms. The study suggests that improving resilience requires shifting from retrospective cost reduction to forward looking governance, with emphasis on digital capability and incentive alignment to enhance capital velocity.

**KEYWORDS:** Financial Resilience; Soft Systems Methodology; Interpretive Structural Modeling; Supply Chain Governance; Wood Fiber Operations

## I. INTRODUCTION

In today's global marketplace, the wood fiber industry is facing pressures that require immediate research attention. Climate driven supply disruptions, geopolitical instability, and fluctuations in biological raw materials have intensified upstream uncertainty. These conditions create irregular production cycles and rising operational costs. As the sector moves toward Industry 5.0 with an emphasis on human centered automation and sustainability, firms must improve supply chain performance to prevent workin g capital from being trapped in the Cash Conversion Cycle. Delays caused by documentation errors, regulatory bottlenecks, and compliance misalignment can immobilize cash and weaken financial stability. Without timely intervention, companies risk serious liquidity challenges in an increasingly competitive global market. Recent analyses indicate that hidden operational costs in post pandemic supply chains have increased by 20 to 30 percent, reinforcing the urgency of this research [1].

The wood fiber industry is selected as the research focus because of its dependence on biological assets and the complexity this creates. Unlike sectors where raw materials are uniform and predictable, this industry relies on living plantations that are affected by seasonality, pests, and climate events. These vulnerabilities distinguish it from conventional manufacturing. Downstream, firms export bulky and low margin products across diverse regulatory environments, generating substantial compliance costs when not managed effectively [2]. These characteristics make the sector a compelling case for developing financial decision-making tools suited to biological uncertainty, with relevance for similar bio-based industries such as forestry and agriculture.

The main variables in this context include biological assets, regulatory compliance, human capital, digital infrastructure, and operational cost leakage. Biological assets shape seasonality and risk exposure, which influence scheduling, Cash Conversion Cycle duration, and cost variation. Regulatory compliance interacts closely with human capital, particularly digital literacy and organizational behavior, to determine how effectively firms respond to evolving requirements. Limited digital capability often leads to slow compliance processes and documentation inaccuracies, creating perceived efficiency gains that do not translate into real financial benefits. Digital infrastructure enables operational improvement but depends on corresponding human capability. Geopolitical conditions can also reshape regulatory requirements, creating nonlinear patterns that traditional financial models do not capture. These interdependencies justify a systems-based approach to mapping relationships and identifying key drivers [3]

Despite the extensive literature on supply chain management, important gaps remain for this sector. Soft Systems Methodology has been applied to explore complex human activity systems, but many applications remain conceptual and lack prioritization tools [4]. Interpretive Structural Modelling provides hierarchical structuring of barriers but is often applied without integrating multiple perspectives or addressing human centered issues [5] [6]. Recent work on Industry 5.0 highlights the need for integrated approaches to improve sustainability [7], yet financial implications in bio-based value chains remain under examined. As a result, the connection between soft variables—such as collaboration, compliance behavior, and human capability—and financial outcomes in the wood fiber industry is still underexplored.

This study responds to these gaps by integrating Soft Systems Methodology and Interpretive Structural Modelling to structure and prioritize financial challenges in the wood fiber industry. By integrating SSM for diagnostic depth and ISM for hierarchical validation, this research moves beyond abstract conceptualization to empirically determine which barriers act as root causes (independent drivers) and which are merely financial symptoms (dependent outcomes). This produces a clearer roadmap for prioritizing variables such as human capital, digital readiness, and regulatory alignment. Expected outcomes include improved capital allocation, reduced hidden operational costs, and stronger cross functional alignment.

## II. LITERATURE REVIEW

To establish a robust financial governance approach to supply chain resilience, this study draws upon three complementary theories: Real Options Theory, Agency Theory, and Information Processing Theory. Together, these theories shift the analytical focus from retrospective cost minimization to prospective capital valuation and incentive alignment [8]. Real Options Theory challenges the traditional view of resilience investments as mere expenses, reframing capabilities like digital infrastructure as strategic call options that provide valuable flexibility in volatile markets, thus justifying capital allocation based on future hedging value rather than immediate cost reduction [9]. Complementing this valuation perspective, Agency Theory diagnoses the root causes of internal friction, revealing that organizational silos are often rational manifestations of principal-agent misalignment where local operational incentives conflict with firm-wide capital efficiency [10]. Finally, Information Processing Theory acts as the structural bridge, validating that financial governance fails when there is a fit gap between external environmental uncertainty and internal data processing capacity, thereby confirming that resilience requires systemic architectural investment rather than tactical budget cuts [11].

### *A. Real Options Theory*

Traditional Discounted Cash Flow (DCF) models often fail to justify investments in supply chain resilience because they view redundancy and digital infrastructure primarily as costs rather than strategic assets [12]. Real Options Theory (ROT) addresses this by positing that in volatile environments (like characterized by geopolitical volatility and regulatory complexity), a firm's ability to delay, switch, or scale operations represents a quantifiable financial option [9].

However, exercising these options requires specific underlying assets to be present within the organization. This research employs Interpretive Structural Modelling (ISM) not to calculate costs, but to mathematically derive the hierarchy of these necessary assets. By categorizing barriers into "Driving Power" and "Dependence Power," ISM is able to distinguish between the Option Premium (the necessary strategic capital investments) and the Payoff (the reduction in financial erosion) [13]. ROT provides the theoretical necessity for this structural mapping, as it argues that operational capabilities must be understood as foundational investments required to hedge against macro-economic risk, rather than mere operational expenses [12]

### *B. Agency Theory*

While ROT addresses the valuation of capabilities, Agency Theory (AT) explains the persistence of internal inefficiencies and the phenomenon of organizational silos. Agency Theory posits that information asymmetry and goal incongruence between a Principal (The Finance Function) and Agents (Logistics and Commercial Managers) lead to suboptimal decision-making, where agents may optimize local Key Performance Indicators (KPIs) at the expense of firm-wide Return on Capital Employed (ROCE) [14].

This theoretical lens necessitates the use of Soft Systems Methodology (SSM) as a diagnostic tool. Unlike hard systems audits which review static outputs or ledgers, SSM's techniques, such as Rich Pictures and CATWOE, are specifically designed to map the divergent Worldviews (W) of stakeholders [4]. By visualizing the friction between the commercial drive for volume and the financial need for margin protection, SSM is uniquely suited to expose the Agency Costs inherent in the system—detecting behavioral misalignments that traditional financial reporting cannot see. Thus, Agency Theory validates SSM as the essential mechanism for uncovering the behavioral roots of financial leakage [15].

### *C. Information Processing Theory*

Information Processing Theory (IPT) provides the rationale for examining technical and data failures within the supply chain. IPT suggests that an organization must align its internal information processing capacity with the information requirements imposed by the external environment. In the bio-industrial context, external drivers such as regulatory complexity and geopolitical volatility generate massive information loads that the firm must absorb [16].

When internal capabilities defined by legacy systems or fragmented data processes fail to match this external load, a structural fit gap emerges, resulting in financial blindness and forecasting errors [11]. The hybrid SSM-ISM approach is critical for diagnosing this gap: SSM qualitatively identifies the manual workarounds used by staff to bridge the deficit, while ISM structurally tests whether internal systems act as the bottleneck preventing the processing of external regulatory data [17]. IPT confirms that financial resilience cannot be achieved by addressing symptoms, but only by ensuring the structural fit between external complexity and internal processing power [18].

By triangulating these theories, this research establishes a rigorous justification for the proposed methodology. Agency Theory necessitates SSM to audit the human and political complexity of the supply chain, while Real Options Theory and IPT necessitate ISM to structure the financial architecture of resilience. This hybrid framework allows the Finance Persona to move beyond retrospective reporting to prospective value engineering [19].

## III. METHODOLOGY

### *A. Research Design*

This study adopts a mixed-methods approach, utilizing a Soft Systems Methodology (SSM) grounded in Interpretive Structural Modelling (ISM). This hybrid design is specifically selected to address the unstructured complexity of the bio-industrial supply chain, where financial leakage stems not from linear operational errors but from systemic behavioral misalignments and structural deficits. The research is descriptive and diagnostic in nature, aiming to map the hierarchical relationships between financial barriers and justify capital allocation strategies.

Primary data was collected through in-depth semi structured interviews with managers at the Riau Mill Complex in Indonesia, which operates as a major vertically integrated wood fiber industrial site. All qualitative verbatim transcripts were then converted into structured barrier codes for the ISM process. The study applied a purposive sampling approach, selecting elite informants who hold direct profit and loss responsibility and strategic decision-making authority. Three experts were chosen in line with the specialist override principle in ISM, which prioritizes depth of expertise over the number of participants. These informants represent the Finance Persona Cluster: the Finance Controller (R10) focusing on capital allocation, hedging, and EBITDA protection; the Procurement Head (R11) focusing on total cost of ownership and supplier volatility; and the Commercial Head (R12) focusing on revenue recognition, green premiums, and customer churn.

### *B. Variables Definition*

The study identifies twelve distinct supply chain barriers, which were then translated into finance focused terminology to align with the Finance Persona, using insights drawn from the interview transcripts.

Table 1. Supply chain barriers definition

| Code | Barriers | Financial Definition | References |
|---|---|---|---|
| B1 | Compliance Burden | The growing cost and effort required to meet changing rules, certifications, and audits. This creates unpredictable compliance spending that acts like a variable overhead on market access. | [29] |
| B2 | Escalating Operation Costs | Increases in production, logistics, and service expenses that directly dilute operating profit and reduce the strength of EBITDA. | [30] |
| B3 | Delays in Deliveries and Billings | Slower product movement and documentation cycles that postpone revenue booking and extend the cash conversion cycle. | [30] |
| B4 | Carbon Liability Accounting | Obligations to track and report emissions, which create a future financial liability as carbon costs, taxes, or penalties become more formalized. | [30] |
| B5 | Global and Macro Uncertainty | External shocks in currency, trade policy, or regional stability that force the company to hold larger working capital buffers and accept higher pricing risk. | [31] |
| B6 | Inefficient Technology | Technology platforms that no longer support fast, accurate, or automated processes. This creates technical debt that slows decision making and increases the opportunity cost of missed efficiencies. | [32] |
| B7 | Human Capital Deficits | A shortage of digital talent and analytical skills that prevents the company from extracting full value from its technology investments and limits return on investment. | [32] |
| B8 | Climate Related Disruptions | Environmental events such as heavy rain, fires, or floods that damage assets, interrupt operations, or trigger inventory write offs. | [31] |

| | | | |
|---|---|---|---|
| B9 | Unpredictable Market Demand | Rapid changes in customer volumes or pricing that disrupt revenue forecasts and create variance between planned and actual top line performance. | [31] |
| B10 | Broken Information Flow | Fragmented information structures that create multiple versions of the truth, reduce forecasting accuracy, and increase the risk of financial blind spots. | [31] |
| B11 | Capacity and Infrastructure Constraints | Infrastructure constraints that limit throughput and restrict revenue generation, often requiring significant capital expenditure to resolve. | [33] |
| B12 | Agency Costs (Internal Misalignment) | Teams working with different targets or incentives, which creates agency costs, duplicated effort, and inefficiencies that ultimately erode financial performance. | [31] |

***C.Data Analysis Technique: SSM-ISM Integration Protocol***

The data analysis follows a two-stage protocol in which soft, interpretive insights are first surfaced through SSM and then formalized into a structured hierarchy using ISM. Each phase contributes a different layer of analytical depth, and the stages do not overlap (Figure 1).

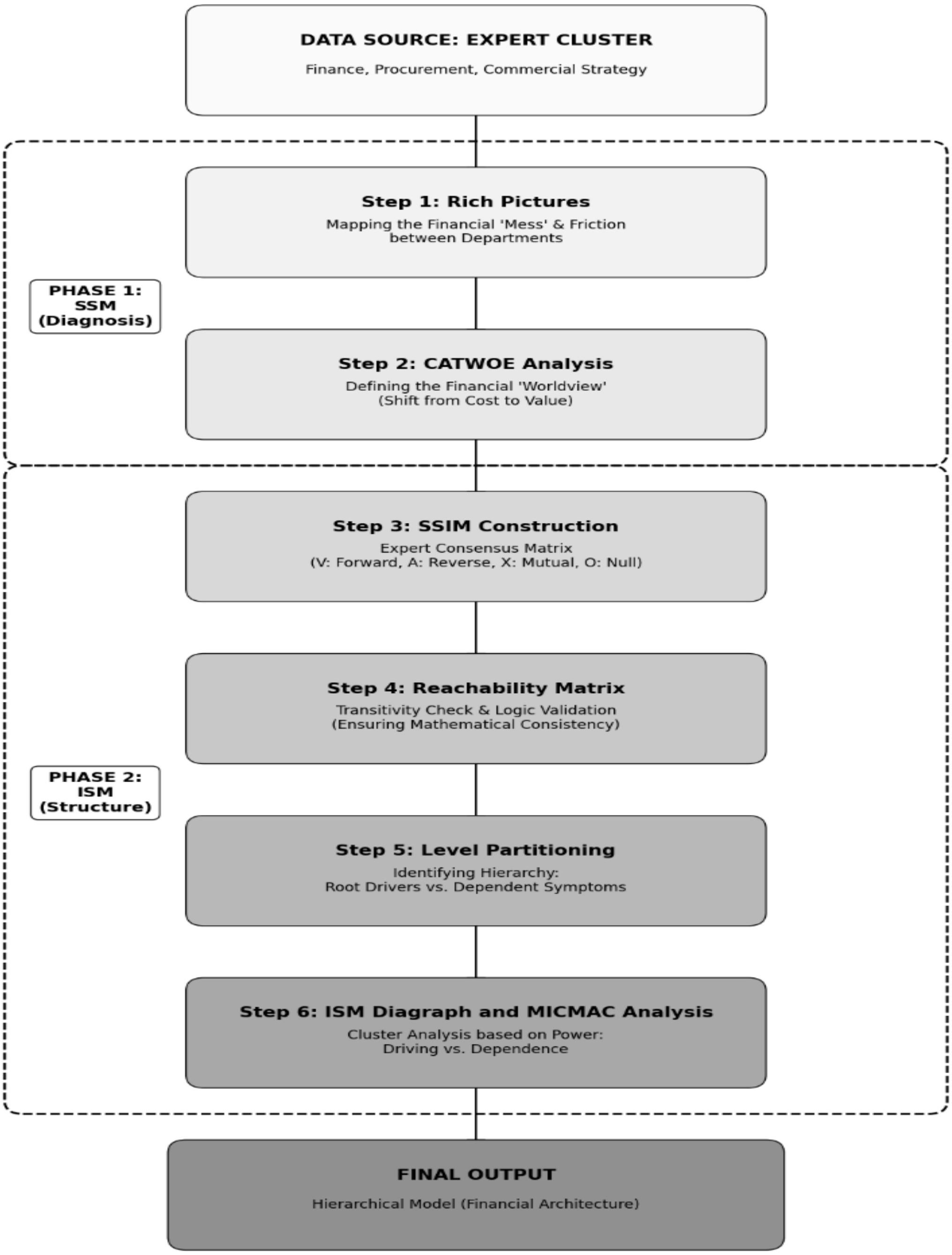


**Figure 1. Steps in SSM-ISM methodology**

**Phase 1: Qualitative Diagnosis using SSM**

In the first phase, the interview transcripts are interpreted using Soft Systems Methodology tools. The process begins with the Problem Expression stage, where Rich Pictures are used to illustrate how value moves through the system and where capital constraints or information bottlenecks appear. These visuals help clarify the practical realities of the supply chain and reveal where financial leakage or delays tend to occur. Next, Root Definitions are constructed using the CATWOE framework. This step makes explicit the worldview of the Financial Persona and reframes the analysis from simply tracking physical throughput to understanding how value accelerates or slows across the system. By articulating the purpose, actors, and environmental constraints, CATWOE provides a structured basis for identifying the core issues that shape financial performance.

In this study, Soft Systems Methodology is applied only up to the development of the Root Definitions intentionally. SSM serves to surface the system's context, draw out the perspectives that matter, and define the scope of analysis. Once this foundation is established, the twelve barriers are specified as the variables of interest, and the reasoning generated through SSM is carried forward into the structural modelling phase. This ensures that the subsequent ISM work is grounded in the real dynamics of the system rather than in assumptions detached from practice.

**Phase 2: Structural Logic using ISM**

In the second phase, the insights and variable definitions derived from the SSM phase serve as the direct input for the ISM procedure, which replaces the traditional conceptual modeling phase of SSM to provide a rigorous, mathematical hierarchy [20]. The process follows four sequential steps:

1. Self-Interaction Matrix (SSIM): This step involves eliciting expert judgements to determine the directional nature of influence between every pair of barriers. The SSIM captures whether Barrier A influences Barrier B, whether the influence is reversed, whether it is mutual, or whether no direct relationship exists. This establishes the foundational interpretive structure of the model.
2. Reachability Matrix (RM): The SSIM is then converted into a numeric binary matrix that represents the presence or absence of influence using 1s and 0s. Transitivity checks are applied to validate that if Barrier A influences Barrier B, and Barrier B influences Barrier C, then Barrier A must also influence Barrier C. This step ensures that the structural logic is internally coherent and mathematically consistent.
3. Level Partitioning: The validated RM is decomposed to identify the reachability, antecedent, and intersection sets for each barrier. Through iterative partitioning, the barriers are assigned to hierarchical levels. This process distinguishes root causes (independent drivers with high reachability) from intermediate linkages and final outcomes (dependent variables with limited driving power).
4. ISM Digraph Construction: A directed hierarchical diagram is then developed using the finalized level structure. This digraph translates the numerical matrix into a visual causal architecture, showing how variables cascade from foundational drivers to intermediate mechanisms and ultimately to downstream financial outcomes with interpretative logic. Following the digraph, the variables are positioned on a Driving Power–Dependence Power grid to assess their strategic significance using MICMAC analysis. This mapping makes it possible to distinguish high-leverage drivers that warrant priority investment from dependent variables that represent observable symptoms rather than root causes.

## IV. RESULTS AND DISCUSSIONS

### *A. Visualizing the Cycle of Trapped Capital By Rich Picture*

The Rich Picture developed from the elite informant interviews (R10, R11, R12) revealed a financial landscape far more complex than the conventional movement of goods across a supply chain. Instead of a clean, linear path from warehouse to customer, the financial picture resembled a circular trap in which value repeatedly accumulates but rarely converts into cash, what this study terms "Trapped Capital" as shown in Figure 2.

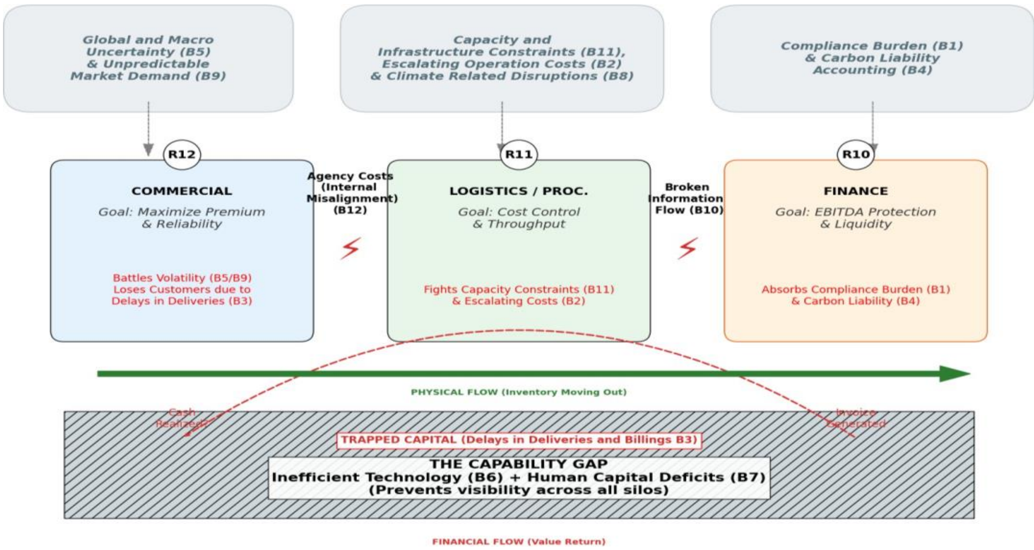


**Figure 2. Rich picture of trapped capital**

The twelve barriers are organized into several thematic groupings that show how pressure builds and interacts across the system:

1. Differentiated External Pressures: The first grouping shows how each function experiences different external pressures, which influence their priorities in distinct ways. Commercial (R12) operates within an environment marked by global uncertainty and fluctuating demand (B5, B9), prompting a focus on sustaining revenue and maintaining customer responsiveness. Logistics and Procurement (R11) face constraints related to capacity, climate-related disruptions, and rising operating costs (B11, B8, B2), which make cost efficiency and execution reliability their central concerns. Finance (R10) manages regulatory and risk-related

requirements, particularly compliance obligations and emerging carbon accounting expectations (B1, B4). These differing external conditions shape functional priorities that do not naturally align and often lead to divergent interpretations of risk and value.

2. Structural Points of Friction: The second layer shows how these differing priorities manifest as structural friction within the system. Commercials seek to secure volume and market position, while Logistics focuses on minimizing operational costs. These contrasting incentives translate into agency costs (B12), where functional optimization can compromise broader organizational performance. At the same time, inconsistencies in information transfer between Logistics and Finance create gaps in visibility (B10). When shipment data is delayed or incomplete, Finance cannot track exposure or verify revenue in real time, leading to delays in financial recognition. These friction points illustrate that internal coordination challenges arise not from isolated communication failures but from deeper incentive and information misalignments.
3. Organizational Capability Limitations: Beneath these interactions lies the Capability Gap, which the Rich Picture positions as the structural foundation of the observed problems. Inefficiencies in technology and limitations in human capital (B6, B7) restrict the organization's ability to achieve cross-functional visibility and timely decision-making. These capability constraints reinforce the misalignment among Commercial, Logistics, and Finance by limiting their ability to share data, coordinate planning, or anticipate disruptions. The analysis suggests that misalignment is rooted not only in the goals of each function but also in the tools and competencies available to support integrative work.
4. Misalignment Between Physical and Financial Flows: presents the contrast between the outward movement of goods and the slower movement of financial value.

- Physical Flow (Green Arrow): Goods move from the mill to the customer with relative consistency.
- Financial Flow (Red Arrow): The recognition of cash is delayed due to issues in delivery confirmation and billing (B3), which lengthen the Cash Conversion Cycle. This visualizes B3 as the ultimate mechanism of "Trapped Capital" because of the Agency Cost (B12) and Broken Information Gap (B10), resulted the Cash Conversion Cycle fails to close efficiently, leaving revenue unrecognized and liquidity frozen.

This interpretation departs from Checkland's [4] classical application of SSM, which typically emphasizes the improvement of operational processes. In this study, the Rich Picture shows that the core challenge is not inefficiency in workflows but a deeper structural misalignment in financial logic, driven primarily by Agency Costs (Internal Misalignment) (B12). This reinforces the view of Fayezi et al. [21], who argue that supply chains are shaped by persistent tensions between principals and agents. Issues that are often described as communication gaps are revealed here as conflicts in financial incentives that weaken the organization's ability to convert assets into return on capital employed.

The extended use of SSM in this research also aligns with the work of Gencoglu et al. [22], who demonstrated the ability of the methodology to uncover human and systemic factors behind organizational deadlocks. By capturing several viewpoints at once, the Rich Picture avoids fragmented understanding and supports a holistic reading of the system, which is essential in complex bio industrial settings where financial and operational realities constantly interact.

### *B. CATWOE Analysis and Root Definition*

Following the construction of the Rich Picture, a CATWOE analysis was conducted to formalize Financial Worldview of the elite informants. This step is essential to distinguish the financial definition of supply chain success from the traditional operational definition. The analysis reveals that for the Finance Persona, the system is not merely about moving physical inventory, but about the transformation of working capital into recognized revenue. shown in Table 2.

**Table 2. CATWOE analysis**

| Element | Definition | Financial Strategy Context |
|---|---|---|
| C (Customers) | The beneficiaries of the system. | Shareholders and Strategic Buyers.<br>The system exists to generate ROI for shareholders and deliver reliability to premium buyers, justifying the cost structure. |
| A (Actors) | Those who execute the transformation. | Cross-Functional Teams (Logistics, Finance, Compliance).<br>These actors often operate in silos, creating agency costs that the system must resolve. |
| T (Transformation) | The conversion of input to output. | Input: Inventory + Working Capital + Regulatory Data. Output: Recognized Revenue + Cash Liquidity.<br>The system transforms at-risk capital into bankable cash. |
| W (Worldview) | The holistic perspective. | The Cash Velocity Engine.<br>Meaning the supply chain is viewed not as a cost center, but as a mechanism for capital turnover. Speed is valued because it reduces the |

| | | |
|---|---|---|
| | | Cash Conversion Cycle. |
| O (Owners) | Those with veto power. | The Board of Directors / CFO.<br>They hold the authority to approve Strategic Capex for digital transformation. |
| E (Environment) | External constraints. | Global and Macro Uncertainty (B5) and Compliance Burden (B1). These are exogenous variables that dictate the baseline cost of operation |

Root Definition.

*A system owned by the Board and operated by cross-functional financial strategists that transforms capital-intensive inventory and regulatory risk into maximized EBITDA and liquidity, by bridging information asymmetries between external global uncertainty and internal operational execution.*

This differs from prior frameworks such as Chand et al. [23], is that anchor system objectives around sustainability compliance. While acknowledging its importance, this study places compliance within a larger financial logic. Compliance becomes a precondition for financial legitimacy and market access, linking to Institutional Theory's idea that organizations must conform to external rules to maintain their license to operate. The emphasis on worldview parallels findings by Parihar & Shankar [24], who demonstrated SSM's role in aligning multiple stakeholder logics in resilience-building. CATWOE thus becomes a bridge between institutional constraints and financial performance.

While the SSM phase effectively clarifies the sources of financial friction, particularly the differing worldviews identified in the CATWOE analysis and the agency related tensions illustrated in the Rich Picture, it also reveals an important limitation for guiding strategic action. The diagnostic outcome shows a network of interrelated issues such as rising operating costs, fragmented information flow, and capability gaps. These issues appear as simultaneous conditions that reinforce one another, but SSM does not indicate which of them drives the others. In this sense, the analysis highlights connections but does not establish an order of influence.

The CATWOE analysis describes an ideal future condition of a more integrated and responsive cash velocity system. However, it does not specify the sequence of interventions required to move from the current state to that preferred condition. As a result, the Finance Persona faces a practical dilemma. Should the organization invest in technology to improve information visibility, or should it first address cross functional alignment to ensure that new systems can be adopted effectively? Because SSM is interpretive by design, it cannot differentiate between a root cause that requires strategic capital investment and a downstream symptom that can be managed through routine operational adjustments.

To address this gap, Interpretive Structural Modelling is used as the next analytical phase. ISM provides a structured method that translates the qualitative insights produced through SSM into a clear hierarchy of influence. By calculating the driving and dependence power of each barrier, ISM identifies which constraints exert foundational influence and therefore need to be addressed first. This hierarchy provides the analytical justification for sequencing interventions and supports evidence-based decisions regarding the allocation of capital and managerial attention.

### *C. ISM and MICMAC Analysis*

*Structural Self-Interaction Matrix (SSIM) Development*

To establish the contextual relationships between the 12 financial barriers, a Structural Self-Interaction Matrix (SSIM) was constructed (Table 3). Three elite informants (R10, R11, R12) evaluated the pairwise relationship between every barrier i and j using four standard logic codes:

- V: Barrier i directly drives Barrier j.
- A: Barrier j drives Barrier i (Reverse influence).
- X: Mutual influence (Feedback loop).
- O: No direct relationship.
  Given the diverse functional roles of the experts (Finance, Procurement, Commercial), a simple majority vote was insufficient. This study applied a Majority & Specialist Override rule to ensure validity.
- Majority Rule: If 2/3 experts agreed on a relationship (e.g., B12 drives B2), it was accepted.
- Specialist Override: If a single expert identified a relationship within their specific domain of authority, it was accepted even without consensus. For example, R10 (Finance) identified that Escalating Costs (B2) freeze capital, preventing Infrastructure Investment (B11). While operational managers might not see this Capital Rationing, it is a valid financial constraint; thus, the relationship B2 □ B11 was coded as valid.

**Table 3. SSIM of the finance and commercial personas**

| i / j | Barriers | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **B1** | **B2** | **B3** | **B4** | **B5** | **B6** | **B7** | **B8** | **B9** | **B10** | **B11** | **B12** |
| **B1** | | V | O | A | A | O | O | O | O | O | O | O |
| **B2** | | | A | A | A | O | A | A | A | X | X | A |
| **B3** | | | | O | O | O | O | A | V | A | O | O |
| **B4** | | | | | O | O | O | O | O | O | O | O |
| **B5** | | | | | | O | O | O | V | V | O | O |
| **B6** | | | | | | | O | O | O | V | O | O |
| **B7** | | | | | | | | O | O | O | O | O |
| **B8** | | | | | | | | | V | O | V | O |
| **B9** | | | | | | | | | | X | O | A |
| **B10** | | | | | | | | | | | A | A |
| **B11** | | | | | | | | | | | | O |
| **B12** | | | | | | | | | | | | |

*Reachability Matrix and Level Partitioning*

The SSIM symbols were converted into a binary Initial Reachability Matrix using standard ISM substitution rules:

- If SSIM is V, then entry (i, j) = 1and (j, i) = 0.
- If SSIM is A, then entry (i, j) = 0 and (j, i) = 1.
- If SSIM is X, then entry (i, j) = 1 and (j, i) = 1.
- If SSIM is O, then entry (i, j) = 0 and (j, i) = 0.

A critical step in ISM is the transitivity check, which posits that if Variable A affects B, and B affects C, then A necessarily affects C. In the context of this research, transitivity reveals indirect financial exposures. For instance, if Global Uncertainty (B5) triggers Compliance Burdens (B1), and Compliance Burdens trigger Delays (B3), the transitivity check mathematically confirms that Global Uncertainty is a root cause of Delays (Table 4). This step transforms the matrix into the Final Reachability Matrix, from which Driving Power (sum of rows) and Dependence Power (sum of columns) are calculated.

To determine the vertical order of the barriers, Level Partitioning was performed. For each barrier, three sets were derived:

1. Reachability Set (Ri): All barriers that barrier i influences.
2. Antecedent Set (Ai): All barriers that influence barrier i.
3. Intersection Set (Ri∩Ai): The common elements.

Barriers where the Reachability Set and Intersection Set are identical (Ri = Ri∩Ai) occupy the top level. These are the Dependent Outcomes or the barriers that result from the system but do not drive it further. Once identified, these are removed, and the process repeats (Table 5).

**Table 4. Reachability matrix after transitivity check**

| i / j | Barriers | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **B1** | **B2** | **B3** | **B4** | **B5** | **B6** | **B7** | **B8** | **B9** | **B10** | **B11** | **B12** |
| **B1** | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 1* | 0 |
| **B2** | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| **B3** | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1* | 1* | 0 |
| **B4** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **B5** | 1 | 1* | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1* | 1* | 0 |
| **B6** | 0 | 1* | 1* | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1* | 0 |
| **B7** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **B8** | 0 | 1* | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1* | 1* | 0 |
| **B9** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **B10** | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1* | 1 | 1* | 0 |
| **B11** | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1* | 1* | 1 | 0 |
| **B12** | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1* | 1 | 1* | 1 |

**Table 5. The level and quadrant of the supply chain barriers**

| Code | Barrier Name | Driving Power | Dependence Power | Reachability Set (Ri) | Antecedent Set (Ai) | Intersection Set (Ri∩Ai) | Hierarchy Level | Quadrant Classification |
|---|---|---|---|---|---|---|---|---|
| B1 | Compliance Burden | 5 | 2 | 1, 2, 3, 10, 11 | 1, 5 | 1 | IV | Independent (Driver) |
| B2 | Escalating Operation Costs | 3 | 8 | 2, 10, 11 | 1, 2, 5, 6, 8, 10, 11, 12 | 2, 10, 11 | I | Dependent (Outcome) |
| B3 | Delays in Deliveries & Billings | 5 | 7 | 3, 2, 9, 10, 11 | 1, 3, 11, 12 | 3 | I | Linkage (Bottleneck) |
| B4 | Carbon Liability Accounting | 1 | 1 | 4 | 4 | 4 | I | Autonomous |
| B5 | Global and Macro Uncertainty | 6 | 1 | 1, 2, 5, 8, 9, 10, 11 | 5 | 5 | VI | Independent (Driver) |
| B6 | Inefficient Technology | 4 | 1 | 2, 6, 10, 11 | 6, 7 | 6 | III | Independent (Driver) |
| B7 | Human Capital Deficits | 1 | 1 | 6, 7 | 7 | 7 | IV | Autonomous* |
| B8 | Climate Related Disruptions | 5 | 1 | 2, 8, 10, 11 | 5, 8 | 8 | III | Independent (Driver) |
| B9 | Unpredictable Market Demand | 1 | 5 | 9 | 3, 5, 9, 10, 12 | 9 | I | Dependent (Outcome) |
| B10 | Broken Information Flow | 5 | 8 | 2, 3, 9, 10, 11 | 1, 2, 6, 8, 10, 11, 12 | 2, 10, 11 | II | Linkage (Bottleneck) |
| B11 | Capacity & Infrastructure Constraints | 5 | 8 | 2, 3, 10, 11 | 1, 2, 8, 10, 11, 12 | 2, 10, 11 | II | Linkage (Bottleneck) |
| B12 | Agency Costs (Internal Misalignment) | 5 | 1 | 2, 3, 9, 10, 11, 12 | 12 | 12 | III | Independent (Driver) |

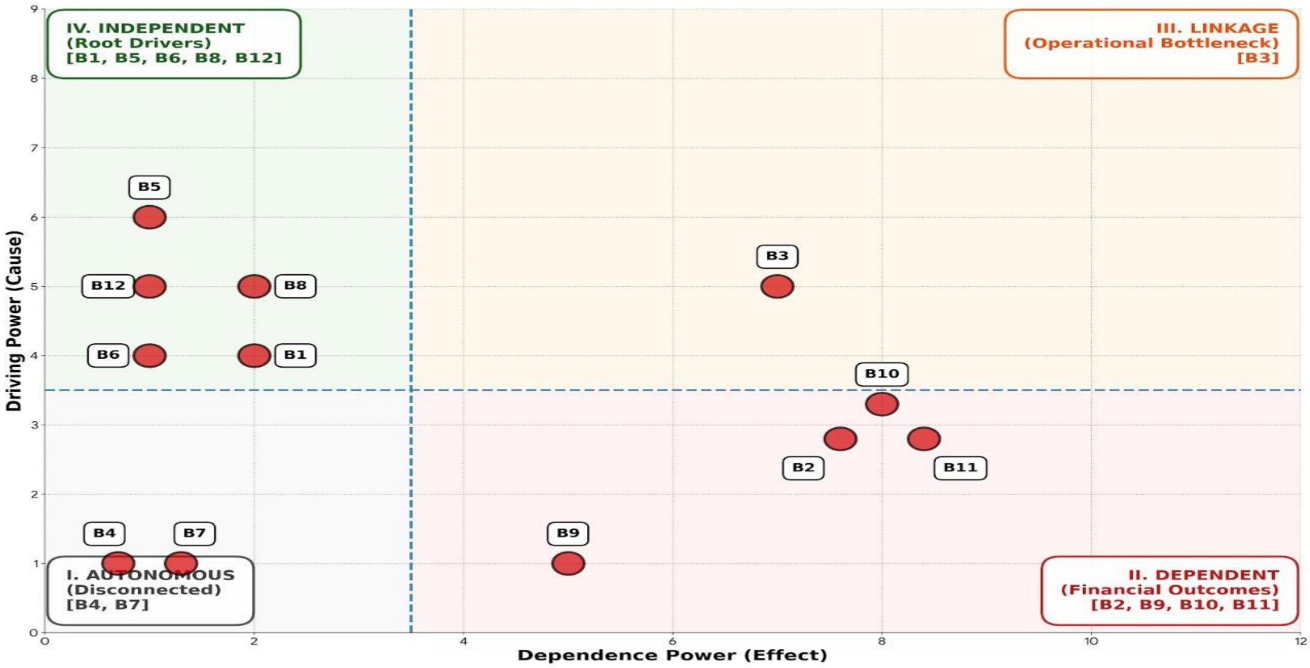


**Figure 3. MICMAC dependence–driving power diagram**

The process of classifying barriers in MICMAC (Matrix of Cross-Impact Multiplications Applied to Classification) analysis involves establishing calibrated thresholds to define quadrant boundaries. These thresholds are typically calculated using the arithmetic mean of the total driving power (the extent to which a barrier influences others) and dependence power (the extent to which a barrier is influenced by others) across all identified barriers. This approach ensures that the divisions are data-driven and reflective of the system's specific distribution of influences, rather than relying on arbitrary cutoffs, promoting a more ac curate representation of interrelationships in supply chain contexts (Soares et al., 2025).

Calibrated Thresholds:

- Average Dependence (X-Axis Threshold): Calculated as the total dependence power divided by the number of barriers (44 /12 = 3.66). This sets the horizontal axis boundary in the MICMAC plot.
- Average Driving Power (Y-Axis Threshold): Similarly computed as the total driving power divided by the number of barriers (44 /12 = 3.66). This establishes the vertical axis boundary.

These thresholds divide the MICMAC diagram into four quadrants, enabling the assignment of each barrier based on whether its driving and dependence powers fall above or below the means (Hasan et al., 2024) as shown in Figure 3. The Independent Drivers (Zone IV) consist of Global Uncertainty (B5), Compliance Burden (B1), Agency Costs (B12), Inefficient Technology (B6), and Climate Related Disruptions (B8). These variables exhibit high driving power and low dependence, confirming their status as the foundational determinants of system behavior. The Linkage barriers (Zone III), composed of Delays in Deliveries and Billings (B3), Broken Information Flow (B10), and Capacity and Infrastructure Constraints (B11), form the unstable feedback layer where causes and effects interact dynamically. The Dependent Outcomes (Zone II), Escalating Operation Costs (B2) and Unpredictable Market Demand (B9), represent the financial symptoms shaped by deeper structural conditions. Meanwhile, the Autonomous barriers (Zone I), Carbon Liability Accounting (B4) and Human Capital Deficits (B7), appear disconnected in the quantitative structure, although qualitative data suggests their indirect involvement. Overall, this configuration demonstrates that the financial outcomes observed by the Finance Persona are not primary problems but emergent consequences of upstream institutional, technological, informational, and organizational dynamics.

The ISM diagraph constructed from the final reachability matrix shows a multilevel hierarchy in which the financial system is driven primarily by a set of foundational variables located at the base of the structure (Figure 4).

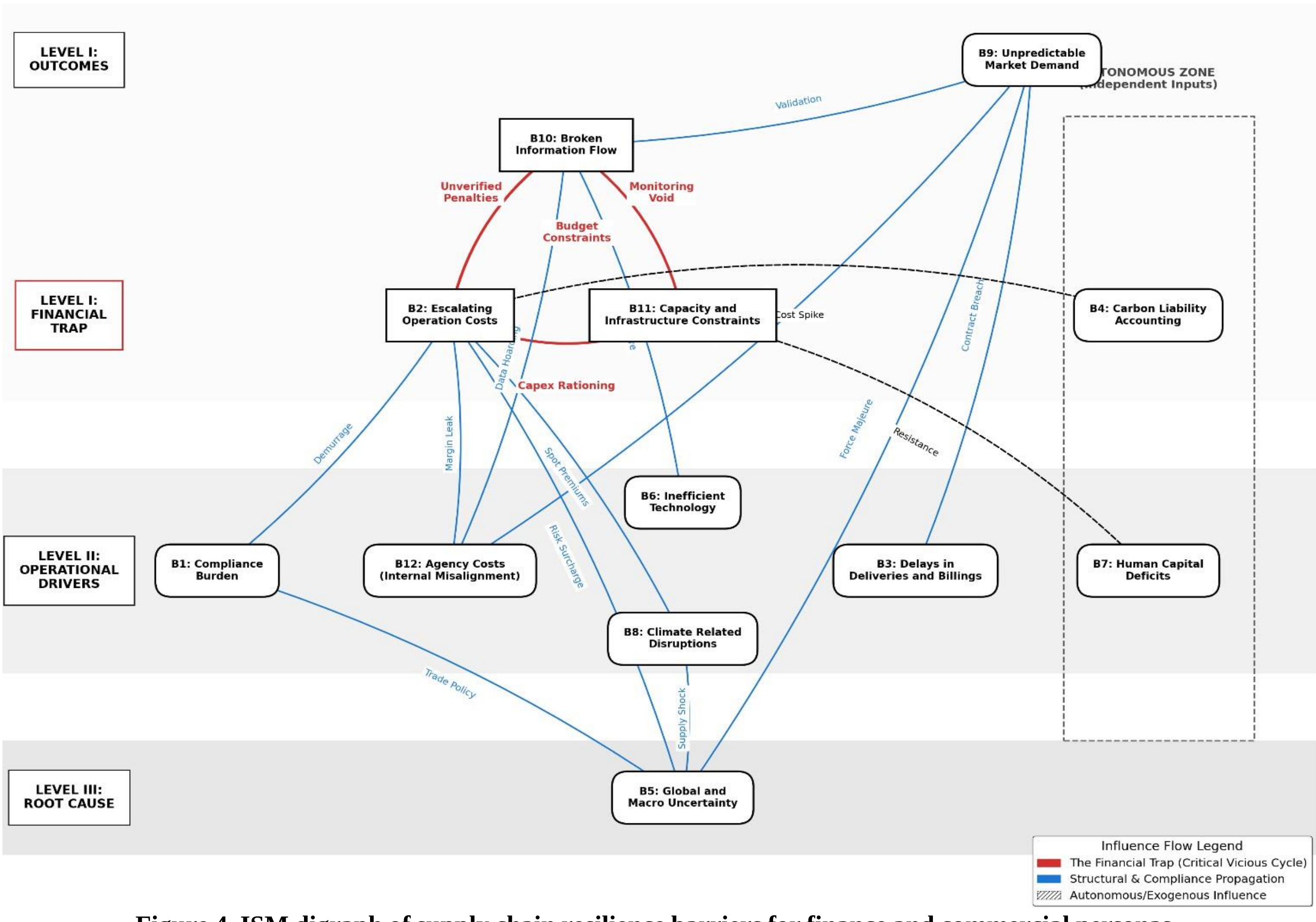


**Figure 4. ISM digraph of supply chain resilience barriers for finance and commercial personas**

***Level III: Global Uncertainty (B5) as the Primary Antecedent***

The ISM digraph identifies Global and Macro Uncertainty (B5) as the only barrier positioned at Level III, making it the most influential antecedent in the structure. Its strong driving power and minimal dependence indicate that it operates as an independent variable that establishes the conditions for all other constraints. This result challenges the common assumption that regulatory pressure is the primary source of stress. Instead, B5 emerges as the origin of systemic disruption.

This finding aligns with Institutional Theory as discussed by Scott, who argues that organizations tend to react to broad coercive and environmental pressures rather than internally produced forces. The financial friction observed in the firm ther efore does not originate from internal mismanagement but reflects turbulence in the global geopolitical and economic environment. In this sense, the organization does not simply incur high costs or slow processes; it inherits uncertainty from its operating context. These findings also support Setyaningsih and Kelle [25], who view regulation and external exposure as fundamental sources of systemic complexity, while diverging from Govindan and colleagues who treat regulatory issues as operational. B5 therefore represents the initiating force that triggers downstream constraints throughout the system.

***Level II: Compliance, Agency, Technology, and Climate Disruptions as Transmission Mechanisms***

The second structural grouping is composed of Compliance Burden (B1), Agency Costs (B12), Inefficient Technology (B6), and Climate Related Disruptions (B8). These barriers form the transmission mechanisms through which the effects of global uncertainty enter and shape internal processes. The digraph demonstrates a direct path from B5 to B1, reframing compliance not as a root cause but as a channel through which volatility becomes institutionalized within the firm. This interpretation aligns with the argument that regulatory requirements become administrative embodiments of external uncertainty. Agency Costs (B12) occupy the same structural position because functional misalignment widens under uncertainty. As volatility increases, each department responds to its own perception of risk, resulting in fragmented priorities and inconsistent decisions. This finding extends Zu and Kaynak [27], who emphasize the role of information sharing in mitigating agency problems, by showing that rising uncertainty can first intensify agency misalignment, which then contributes to information breakdown. B12 therefore acts as a converter of external turbulence into internal inefficiency.

***Level I: The Financial Trap as a Recurring Internal Feedback Structure***

At the lowest structural grouping, the ISM model identifies a reinforcing loop linking Escalating Operation Costs (B2), Capacity Constraints (B11), and Broken Information Flow (B10). These barriers form an internal feedback structure in which each constraint amplifies the others.

From a systems perspective, this reflects circular causality. Rising operational costs reduces the organization’s capacity to invest in infrastructure, which further weakens operational capability. Reduced infrastructure capacity limits data generation and visibility, restricting the finance function’s ability to assess expenditures and optimize performance. The resulting information gaps then contribute to further cost escalation. The loop stabilizes into a self-reinforcing state of inefficiency, consistent with the financial trap described in your SSM analysis. This has direct managerial implications. Addressing any of these issues individually, such as through cost cutting alone, will not break the cycle because the reinforcing mechanism originates from Level II. Sustainable improvement requires intervention at the structural drivers that feed the loop, rather than at the symptoms that emerge from it

*Autonomous Zone: Human Capital (B7) as a Structural Constraint on System Capacity*

Human Capital Deficits (B7) appear in the autonomous zone of the digraph, indicating that while they interact with the system, they are not significantly influenced by other barriers. Skill limitations are typically seen as operational drivers, yet their structural independence suggests that they function more as external constraints on the firm’s ability to respond to uncertainty.

This interpretation corresponds with the Resource Based View, which positions human capability as a central determinant of organizational responsiveness and adaptability. B7 places a ceiling on the system’s absorptive capacity. As external uncertainty increases, the level of internal capability determines how effectively the organization can process information, resolve cross functional conflicts, and manage operational disruption. These findings resonate with Belhadi and colleagues, who emphasize that digital maturity depends on analytical and decision-making competencies rather than the availability of tools alone, while also challenging technology centered perspectives such as Attiany [26]. B7 therefore limits the system’s overall ability to manage disruption rather than causing disruption directly.

*Market Demand (B9) as the Terminal Indicator*

Unpredictable Market Demand (B9) sits at the end of the ISM structure as a highly dependent barrier with minimal influence on others. It absorbs the combined effects of all preceding constraints without sending influence back into the system. This confirms that market volatility is not a driver but an outcome variable that reflects the system’s overall performance.

Revenue variability becomes a measurable indicator of deeper structural issues. When the system fails to absorb external pressures or coordinate internal processes, these failures surface as unstable demand outcomes. In this sense, B9 offers a practical measure of how effectively the organization manages the multi-level pressures that originate from higher structural positions.

## V. CONCLUSIONS

This study applied a hybrid Soft Systems Methodology and Interpretive Structural Modeling approach to transform a complex set of interacting financial and operational variables into a clear and validated structural model. The analysis identified the core causal architecture by separating the deep structural drivers, such as Global and Macro Uncertainty (B5), Compliance Burden (B1), and Agency Costs (B12), from the surface level outcomes such as Escalating Operation Costs (B2) and Delays in Deliveries and Billings (B3), which are more visible yet less influential. The hierarchical mapping reinforced this understanding by showing that the top-level strategic drivers, particularly human capital and governance alignment, are the points where managerial and policy action can generate the greatest effect on Return on Capital Employed. The results provide a practical foundation for strengthening financial resilience by directing attention to the most influential structural factors rather than addressing only the symptoms of margin erosion.

Theoretically, this study contributes to the literature on supply chain resilience and financial governance by moving beyond static barrier identification. By integrating Agency Theory, Real Options Theory, and Information Processing Theory, the findings show that internal misalignment and information asymmetry are the main sources of financial leakage. The study challenges the common view that high costs reflect operational failure. Instead, it positions them as dependent outcomes shaped by the fit gap between external geopolitical volatility and internal processing capabilities. Practically, the study offers three strategies for managers:

1. Strengthen governance rather than reduce spending. Managers often respond to Escalating Operation Costs (B2) by cutting logistics budgets. The analysis shows these costs are outcomes, not root causes. Resources should be directed toward addressing Agency Costs (B12) and Broken Information Flow (B10). Improving incentive alignment between Commercial and Logistics teams is a structural intervention that reduces value leakage, consistent with Agency Theory.
2. Treat human capital as a strategic option. The strong relationship between Human Capital Deficits (B7) and Inefficient Technology (B6) indicates that digital transformation is primarily a capability issue. Following Real Options Theory, investment in digital skills should be viewed as acquiring a strategic option that enables the organization to capture the value of its technology investments.
3. Build buffers against external volatility. Global and Macro Uncertainty (B5) is an independent driver that cannot be controlled, but its financial effects can be managed. Shifting from static budgeting to dynamic scenario planning allows the organization to absorb fluctuations in Compliance Burdens (B1) without disrupting the cash conversion cycle.

Several limitations should be noted. The contextual relationship matrix relied on expert judgment from a specific Financial Strategy cluster, which is interpretive by nature and shaped by the imperative to protect profit. Although the process was supported by systematic elicitation and transitivity validation to maintain logical consistency, the model reflects a specific worldview that prioritizes capital efficiency over pure operational throughput. The set of barriers examined was also intentionally constrained to keep the analysis focused on financial governance. Other relevant technical or engineering variables may exist and could be included in future work to broaden the structural view.

A wider set of personas would deepen the interpretive strength of the ISM structure and offer a richer multi-stakeholder perspective on the barriers for future research. Additionally, future studies could employ Structural Equation Modeling (SEM) to statistically quantify the financial impact of the relationships identified here, specifically measuring the correlation between Agency Cost Reduction and EBITDA Improvement across the wider agrobiomass processing industry.

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