

Navigating Challenges for Supply Chain Transparency in Digital Enterprises

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Abstract

Purpose: In the age of digital businesses, the rise of innovative digital transformation has made supply chain transparency (SCT) an essential research topic. While digital technologies provide possibilities for enhancing transparency in supply chains, there is limited research on how digital businesses overcome different SCT issues or provide real-time visibility and traceability. This research investigates the different challenges of transparency in supply chains for digital businesses in the age of digital transformation.

Design/methodology/approach: Challenges are identified through a comprehensive literature review and finalized through the fuzzy-Delphi method (FDM) after industry experts' validation. Data is gathered, ranked and prioritized through the analytic hierarchy process (AHP) entropy method.

Findings: The study reveals that challenges related to data privacy and security, supplier resistance, and lack of data standardization grouped under Cluster 1 (Critical Digital Friction Points) pose the most significant barriers to supply chain transparency in digital enterprises. These are followed by Cluster 2 (Operational Capability Gaps) and Cluster 3 (External and Strategic Constraints), highlighting a clear prioritization framework for addressing SCT issues in a structured, phased manner.

Implications: By leveraging advanced digital technologies to gather, share, and analyze supply chain data, digital enterprises can overcome these challenges, enhance operational effectiveness, and gain stakeholders' trust. These findings can be utilized by policymakers to develop guidelines that enhance transparency while maintaining data security. Practitioners can develop targeted strategies to address supplier resistance and infrastructure deficiencies.

Originality: This study makes three distinct contributions. Firstly, it fills a gap in current literature by initiating a clear debate on supply chain transparency beyond generic or sustainability-focused models, illuminating its unique dimensions in digital enterprises. Secondly, it demonstrates the practical importance of SCT by identifying and prioritizing the key challenges that are faced by digitally transforming companies. Thirdly, it advances theory by contrasting traditional perspectives with new insights drawn from our findings, offering both actionable guidance and novel conceptual frameworks for transparency in digitally enabled supply chains.

Keywords: Supply Chain Transparency, Digital Enterprises, Digital Transformation, AHP, Entropy Method

1. Introduction

The growth of digital firms and advancements in digital technologies have significantly influenced the role of supply chain transparency (Adhi Santharm and Ramanathan, 2022; Jia et al., 2024; Morgan et al., 2023). Supply Chain Transparency (SCT) is sometimes interchangeably referred to as visibility and traceability, but the literature draws significant distinctions¹. Visibility is commonly used to denote an internal access capability to real-time supply chain information, whereas traceability encompasses the ability to trace the origin, movement, or conformity of a product along the supply chain (Wadhwa et al., 2010; Budler et al., 2024). Conversely, SCT involves intentional revealing of supply chain details, both within and outside the organization, for the purposes of building confidence, responsibility, and ethical confluence (Beulens et al., 2005; Montecchi et al., 2021). Within digital businesses, SCT assumes additional facets - platform interoperability, algorithmic openness, and digital data stewardship - beyond classic assumptions based on physical trackability or stock visibility². This research applies SCT as the strategic, technology-enabled revelation of truthful and actionable supply chain information across organizational borders.

The application of digital transformation has increased the business capacity for realizing and communicating SCT (Ye et al., 2024). Greater transparency simplifies proactive decision making; companies can avoid disruptions, correct quality-related problems, and make the environment sustainable (Chen et al., 2022; Schäfer, 2023). Both customers and companies equally benefit from transparency since it contributes to trust, improves brand reputation, and supports informed decisions (Boehme et al., 2024). Firms are able to achieve greater operational efficiency and competitiveness, while consumers can be provided with trustworthy information that guarantees a better choice of goods and greater customer satisfaction (Wang et al., 2024). SCT builds consumer-business trust, boosts operational effectiveness, and fosters innovation, apart from promoting ethical consumption. It also empowers consumers in independent decision making in conformity with their values (Zhou et al., 2024). It facilitates bottleneck identification and streamlines procedures, thereby fostering innovation in the manufacturing and logistics sectors (Yu et al., 2024; Iranmanesh et al., 2023). For group

¹ <https://www.ibm.com/think/topics/supply-chain-transparency> (Accessed on 31st July 2025)

² <https://www.gartner.com/en/supply-chain/customer-success-stories/building-a-culture-of-transparency-in-supply-chain> (Accessed on 31st July 2025)

decision making and problem solving, SC transparency promotes multi-stakeholder cooperation with shared objectives, allowing businesses to engage with suppliers, NGOs, customers, and government organizations efficiently (Chi et al., 2024; Schäfer et al., 2023).

Businesses can invest in digital tools and technologies as well as infrastructure for data collection, validation, and data sharing among stakeholders to achieve SC transparency (Moraes et al., 2025). Customers and regulators play a crucial role in promoting transparency. SCT highlights the positive impact that disclosure has on the long-term survival of organizations, society's well-being, and long-term environmental sustainability (Lerman et al., 2024).

Customers can now access more detailed product information, such as background and current market influence, with greater convenience due to the emergence of digital platforms (Budler et al., 2024; Yang & Lu, 2024). To foster transparency, companies actively engage customers to encourage ethical consumption (Budler et al., 2024; Yang & Lu, 2024). Digital companies can communicate with customers, use information based on real data to identify opportunities for supply chain optimization (Chen et al., 2019; Ahmed and Omar, 2019; Sodhi and Tang, 2019). The iterative cycle enables process streamlining, wastage reduction, and sustainability stimulation, which supports an overall open and ethical supply chain (Chen et al., 2019). Advanced data analytics software is used by online businesses to manage the vast amounts of information generated along the supply chain. Businesses are able to identify patterns, forecast future disruptions, and improve operations based on data analysis. It heightens the overall supply chain effectiveness and visibility.

Internet of things (IoT), sensors, devices, and radio frequency identification (RFID) tags are a few of the technologies that digital companies employ to collect real-time data throughout the supply chain (Ponte et al., 2020; Zelbst et al., 2020). Such data provides precise information, such as the position of a product, temperature, humidity, etc. The real-time exchange of such information offers stakeholders real-time access to information about the movement and status of products, raising transparency (Garcia-Torres et al., 2024). Advanced digital platforms offer businesses the means to verify the legitimacy and ethical performance of their suppliers through evaluating certifications, regulatory compliance, and social and environmental standards (Chod et al., 2020; Wu and Yu, 2023). Though a lot has been done on SCT literature, a few gaps have not yet been filled. For example, many research studies (Li *et al.*, 2024; Liu, Chen, *et al.*, 2024; Liu, Zhou, *et al.*, 2024) focus on transparency practices in

larger organizations; however, there is a need to study how digital enterprises overcome SCT challenges. Additionally, while digital transformation provides solutions for enhancing transparency (Ebinger and Omondi, 2020), the study should also focus on difficulties and potential risks related to their applications, such as data privacy issues, cybersecurity, and technology adoption barriers. While coordination among supply chain partners is frequently necessary for transparency, more research might explore the drawbacks and advantages of information sharing across various organizations with different goals. Digital enterprises often make use of a range of platforms and technologies. The establishment of industry-wide standards for data interchange and transparency, as well as the potential and problems for interoperability that come with integrating these technologies, is lacking in previous literature.

While SCT has been much debated in the literature, most existing research focuses on sustainability or risk within conventional supply chains. However, digital companies natively constructed on digital infrastructure face distinct transparency challenges related to real-time data harmonization, cross-platform coordination, and the establishment of digital trust. These socio-technical complexities are underrepresented in current research, which often overlooks the nuanced demands of digitally native systems. Moreover, to the best of our knowledge, no prior studies have systematically prioritized SCT challenges specific to digital enterprises using expert validation from industry practitioners. Existing literature also lacks efforts to cluster these prioritized challenges into meaningful categories to guide managerial decision-making. Our research bridges this divide by identifying and ranking SCT challenges specifically for digital businesses and offering a categorized structure validated through an expert-driven approach. By addressing these research gaps, researchers will be able to understand how SCT is changing within the context of digital enterprises.

To fill the above gaps in literature, the following questions will be addressed.

RQ1: What are the primary challenges to SCT in businesses, and how can these challenges be tackled?

RQ2: How are SCT challenges prioritized and categorized to support strategic decision-making in digital enterprises?

The objectives below are framed to answer the above research questions.

RO1: To identify and prioritize the challenges of SCT in businesses.

RO2: To provide recommendations and guidelines for digital enterprises utilizing digital transformation to improve SCT.

In this work, past published papers are studied to identify various challenges for SCT. These challenges are then validated through the fuzzy-Delphi (FDM) method in the next phase. Initially, thirteen challenges are identified, with three challenges eliminated after applying the fuzzy-Delphi method and validation from industry experts. The final list of ten challenges is then used for further prioritization using the AHP-entropy method. This method is a *multi-criteria decision-making (MCDM)* technique that combines the analytic hierarchy process with the concept of entropy. Decision-makers can use both subjective and objective elements in their decision-making process. Entropy can measure the uncertainty or objectivity associated with each criterion, while AHP is particularly effective at handling subjective judgments. This study opens a focused debate on supply chain transparency in digital enterprises, identifies and prioritizes practical SCT challenges, and offers new theoretical insights by contrasting traditional views with findings from digitally enabled contexts. Doing so can help practitioners gain a better understanding of the complexity surrounding SCT.

The remainder of the paper is structured as follows: Section 2 continues with a literature review. In section 3, the research methodology is described. Section 4 presents the findings and discussion. Section 5 considers the implications, followed by a conclusion in Section 6.

2. Literature Review

2.1 Concept of Supply Chain Transparency

SCT holds significant importance in contemporary SCM across various industries. Emerging literature differentiates supply chain visibility, traceability, and transparency. Traceability is defined as the technical capability to track materials, products, or processes throughout a supply network (Mol, 2015; Yang & Lu, 2024), while visibility is concerned with data flow and access within the organization (Wadhwa et al., 2010; Zhu et al., 2018). Transparency, on the other hand, involves the voluntary disclosure of pertinent supply chain information to outside parties - customers, regulators, or civil society with a view to raising accountability and moral performance (Budler et al., 2024; Boehme et al., 2024). SCT in digital supply chains also has to consider data privacy concerns, share in real time, and allow cross-platform communication, distinguishing SCT qualitatively from previous transparency frameworks based on regulatory disclosure or product traceability. Our research addresses this burgeoning change by concentrating on SCT challenges characteristic of digitally empowered

businesses. While transparency initiatives are historically driven by concerns about quality, safety, and legal requirements, the past decade has witnessed the emergence of new requirements stemming from efforts toward collaborative operational improvement and the promotion of environmentally and socially responsible supply chains (T. Li et al., 2014; Faisal et al., 2024). The degree to which a supply chain participant has access to pertinent information on goods, processes, and capital movements, characterized by minimal loss, distortion, delay, or noise, is referred to as SCT (Beulens; *et al.*, 2005). Thereby, SCT is a pointer for the accuracy, precision, availability, accessibility, and up-to-date condition of supply chain information (Faisal et al., 2023). In addition, major supply chain stakeholders such as customers, government authorities, or shareholders may be provided with vital information speedily, extensively, credibly, and coherently (Wadhwa et al., 2010).

2.2 Challenges in Digital Supply Chains

Although there are significant benefits to SCT for all stakeholders across the supply chain, as noted by Bastian and Zentes (2013), effective SCT can be jeopardized by cultural and linguistic differences. Supply chains tend to span multiple countries and regions in the modern global corporate environment, each with its own cultural norms and languages. Birkey et al. (2018) also identify inconsistencies that might lead to misinterpretation, misrepresentation, or communication issues, all of which hinder the free flow of information. In addition, research conducted by Duan and Aloysius (2019) argues that investors perceive scenarios in which particular information emerges and amplifies a company's political and social prominence as negative. In addition to this, Wood et al. (2017) elaborate that under this paradigm, the notion of SCT would have to be constantly enhanced to catch up, since just trying to make systems better through iterative solutions will not work to overcome the challenges based on partner trust and distrust in the supply chain.

In the same way, Morgan et al. (2023) examine how the competing values theory might be employed to contrast the utilization of voluntary openness and obligatory transparency in solving a prevalent issue of data privacy. The more data capture points there are scattered throughout a company's supply chain network, the higher the vulnerability to unauthorized access. Even reliable partners fall prey to this weakness, and they could end up being the victim of hacker attacks (Egels-Zandén et al., 2015; Liu, Du, et al., 2024). The current work also shows that a lack of advanced analytical capabilities and implementation of inclusive data harmonization are the crucial barriers to attaining SCT (Zhu et al., 2018). Such challenges

should be overcome to unlock the potential of operational effectiveness, responsiveness, and enhanced decision making in supply chains (Carter and Rogers, 2008).

In order to enable SC transparency, effective communication, stakeholder confidence building, strategic disintermediation, and supply chain integration are recommended for companies (Ahmed and Omar, 2019). Technological infrastructure is also seen as being among the largest SC transparency challenges. Poor or inefficient technological infrastructure can lead to errors, delays, and inefficiencies in data sharing (Kumar et al., 2022; Zelbst et al., 2020; Sunny et al., 2020). Bai and Sarkis (2020) also conclude that the sharing of real-time information is problematic, resulting in errors, delays, and inefficiency in data sharing among stakeholders because of obsolete infrastructure technology. Resistance by suppliers is also a hindrance to supply chain operational transparency because suppliers consider it an essential element of their competitive edge. Suppliers adopt a defensive stance with regard to their confidential information (Guan et al., 2020; Wang et al., 2024). Internal operations, sourcing strategies, and price information may be denied, based on concerns about disclosing sensitive information, potential security weaknesses, or weakened bargaining positions (Ada et al., 2021). This hostility reduces their ability to exchange information freely across the supply chain network, affecting collaborative attempts to increase transparency (Malik et al., 2021). Gualandris et al. (2021) further suggest that to counteract this issue, one should create trust, guarantee confidentiality, and emphasize the positive effect of transparency to both parties. Establishing strong levels of communication and employing incentives for interaction reduces the anxieties of suppliers and builds a more transparent and peaceful supply chain culture (Montecchi et al., 2021). Rajput (2024) illustrates the industry 4.0 enablers for sustainable SCT through the application of systems and information processing theories.

From the above analysis of the many hindrances to achieving SCT, it is clear that resolving these problems is of utmost importance. The smooth flow of information needed for transparency initiatives is hindered by suppliers' reluctance to share proprietary data, fear of losing a competitive advantage, and the sophisticated technical environment (Iranmanesh et al., 2023; Pinnington et al., 2023; Schäfer, 2023; Zheng et al., 2024). In addition, the intricacy of regulatory systems, cultural diversity, and legal problems aggravate these challenges. Given such obstacles, it is indispensable to recognize the imperative need to overcome them. Emphasis on risk reduction, effective operations, stakeholder trust, and the encouragement of sustainable practices represents a compelling case for actively eliminating these hurdles.

2.3 Role of Digital Technologies in Enhancing SCT

Although the above critique outlines some technological and operational issues that affect SCT, a more subtle appreciation hinges on synthesizing theoretical explanations as to why the problems exist and how digital businesses react to them. The dynamic capabilities theory offers a valuable framework to explain how digitally dynamic environments shape the way organizations construct, reorganize, and coordinate internal and external competencies to deal with transparency. Examples of capabilities that become essential in sensing and reacting to transparency issues in real time include data integration, coordination with suppliers, and digital infrastructure flexibility.

From the stakeholder theory view, SCT is not merely a technical problem but also relational and ethical. Stakeholders such as suppliers, customers, regulators, and NGOs have different expectations of transparency. Suppliers' resistance or data-sharing reluctance generally stems from conflicting stakeholder goals which are identified and ranked in this research. Institutional theory clarifies how environmental pressures, regulated mandates, industry norms, and customer scrutiny drive SCT adoption. Digital companies are increasingly faced with coercive (e.g. data privacy regulation), normative (e.g. ESG pressures), and mimetic (e.g. peer benchmarking) pressures to institutionalize transparency. This research contributes to existing literature by integrating these insights and empirically distinguishing and ranking SCT challenges that arise at the crossroads of capability deficiencies, stakeholder incongruence, and institutional pressures. In contrast to previous literature that tends to isolate single factors or technologies, our research provides a comprehensive perspective that is theory-based and authenticated through expert feedback.

Previous studies on SCT tend to concentrate on sustainability (Boehme et al., 2024), compliance with modern slavery (Pinnington et al., 2023), or risk management of global sourcing (Egels-Zandén et al., 2015; Lohmer et al., 2020). These works, while beneficial, tend to research SCT theoretically or from compliance/registry angles, having less interaction with digitally native business models or data-based coordination problems. Developments in digital technologies have created new pathways to improve transparency throughout supply chains. Blockchain, for example, offers immutable and verifiable ledgers that minimize information asymmetry and allow traceability (Queiroz & Wamba, 2019; Saberi et al., 2019). Internet of

Things (IoT) devices support real-time monitoring of processes and products, thereby meeting visibility issues (Bag et al., 2020). Big data analytics platforms also enable companies to forecast disruptions, enhance decision-making, and enhance stakeholder confidence (Mandal, 2020). Yet, despite such technological progress, digital businesses, particularly from emerging markets, must contend with contextual impediments like regulatory uncertainty, constrained digital capabilities, and infrastructural issues, which still prevail in undermining transparency in practice.

2.4 Theoretical Foundations

To offer a strong conceptual foundation for an examination of SCT challenges in digital businesses, this research employs a multi-theoretical approach that synthesizes Principal Agent Theory, Stakeholder Theory, and Dynamic Capabilities Theory. Principal-Agent Theory (Eisenhardt, 1989) explains how asymmetries in information and differences in interests between purchasers and suppliers may lead to opportunistic actions by parties and act against transparency efforts. Stakeholder Theory (Freeman, 1984) asserts that companies are under pressure from various stakeholders such as customers, regulators, NGOs, and supply chain partners who tend to hold divergent expectations on transparency and disclosure. Dynamic Capabilities Theory (Teece et al., 1997) is a view that describes how digital businesses construct, reconfigure, and deploy technological and relational capabilities to sense, seize, and transform transparency practices in fast-changing environments. While Principal-Agent Theory emphasizes transparency as a mechanism to mitigate opportunism, Stakeholder Theory views it as a response to diverse and often conflicting stakeholder demands. In contrast, Dynamic Capabilities Theory reframes transparency not as a static compliance mechanism, but as an evolving strategic capability. This theoretical divergence underscores the need to reconceptualize SCT beyond compliance or governance, toward dynamic adaptation in digital ecosystems. Together, these theories inform our identification and prioritization of SCT challenges by explaining not only why such challenges emerge, but also how firms develop capabilities to address them. Despite the relevance of these theoretical perspectives, prior research rarely integrates them to systematically analyse SCT challenges specific to digital enterprises. This theoretical integration helps bridge existing research gaps by offering a more holistic lens to understand both the emergence and prioritization of transparency barriers.

This integrative framework guides the analysis and interpretation of results in the subsequent sections. In addition, while SCT barriers have often been characterized by

frameworks and qualitative research (e.g., Mol, 2015), few have resulted in quantitatively ranked action plans. Our research bridges this shortcoming by presenting a hybrid model that incorporates both subjective expert judgment and objective decision weighting. This makes our research both methodologically innovative and practically relevant, presenting prescriptive value to digital businesses aiming for the implementation of transparency solutions. While previous research provides significant theoretical contributions to uncovering transparency issues in supply chains, most of them are conceptual in nature or centred around sustainability and regulatory concerns. This research, however, presents a pragmatic, expert-based framework (refer to Figure 1) blending subjective and objective evaluation to rank the priority of transparency issues in the context of digitally empowering enterprises. This methodology not only improves the clarity of decision-making but also addresses a literature gap by operationalizing SCT prioritization with hybrid logic in the context of real-world constraints.

To identify the relevant challenges, we conduct a comprehensive review of prior academic literature by consulting the Scopus and Web of Science databases. Only articles published in English are considered for inclusion. An initial pool of 67 articles is retrieved using a Boolean combination of keywords such as “*digital transformation*,” “*digital enterprises*,” “*supply chain*,” “*transparency*,” and “*traceability*.” The inclusion criteria requires that studies explicitly discuss transparency or traceability challenges in digital supply chains, while articles focusing exclusively on unrelated topics such as e-commerce marketing or purely technical system development are excluded. After screening abstracts for relevance and applying these criteria, 36 articles are selected for in-depth analysis. From this set, 13 distinct challenges are systematically identified, as presented in Table 1.

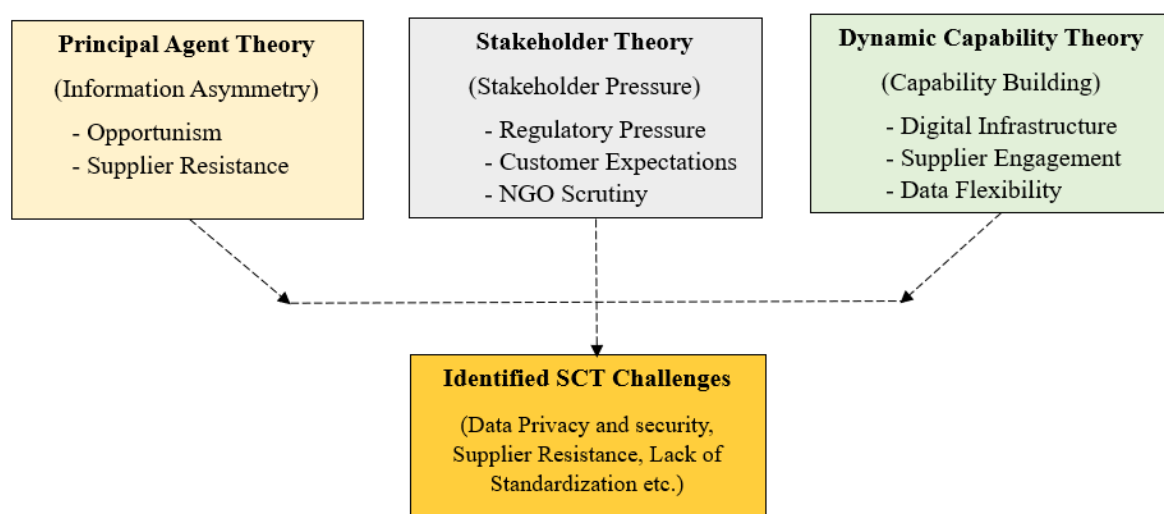


Figure 1: Framework for SCT Challenges

Table 1: List of challenges for supply chain transparency for digital enterprises

Challenges	Description	References
Cultural and Language Differences	Variations in cultural norms and language barriers among supply chain partners can lead to miscommunication and misunderstandings, complicating transparency efforts.	(Joo et al., 2024; Doetzer, 2020)
Lack of Technology Infrastructure	Insufficient or outdated technological resources hinder the ability of enterprises to implement advanced digital solutions for transparency.	(Saberi et al., 2019; Xu et al., 2021)
Concerns with Competitive Advantage	Organizations may be reluctant to share data openly due to fears of losing their competitive edge or exposing sensitive operational details.	(Budler et al., 2024; Mol, 2015; Zheng et al., 2024)
Supplier Resistance	Suppliers often resist adopting new transparent procedures due to concerns over cost, lack of knowledge, or disruption to existing practices.	(Boehme et al., 2024; Lohmer et al., 2020)
Supply Chain Disruption Risk	Unexpected events such as natural disasters or geopolitical tensions can disrupt supply chain operations, reducing transparency and traceability.	(Lu et al., 2022)
Complexity of Supply Chain	Large, global, and interconnected supply chains make it challenging to achieve uniform visibility across all tiers and stakeholders.	(Budler et al., 2024; Zheng et al., 2024)
Lack of Data Standardization	Inconsistent data formats and reporting standards across supply chain entities hinder seamless data integration and transparency.	(Bag et al., 2023; Behnke & Janssen, 2020)
Data Privacy and Security Issues	Concerns over unauthorized access, cyberattacks, and misuse of shared information create barriers to transparent supply chain practices.	(Budler et al., 2024; Xu et al., 2021)
Regulatory and Legal Challenges	Variations in laws and regulations across regions impose additional burdens on organizations striving to maintain transparency.	(Ahmed and Omar, 2019; Bai and Sarkis, 2020; Chen et al., 2019)
High Cost and Time Consumption	Implementing transparency measures often involves significant financial investment and time, deterring organizations from pursuing them.	(Wu and Yu, 2023)
Unavailability of Skilled Resources	A shortage of personnel skilled in digital technologies and supply chain management limits the effective implementation of transparency initiatives.	(Bag et al., 2020; Iqbal and Ahmad, 2022; Jia et al., 2024)
Lack of Stakeholder Pressure	Weak or absent pressure from stakeholders, including customers, investors, and governments, can reduce the urgency for transparent supply chains.	(Budler et al., 2024; Liu et al., 2024)

Limited Accountability	Ambiguity in roles and responsibilities within the supply chain ecosystem can hinder efforts to ensure transparency and compliance.	(Montecchi et al., 2021; Karaman et al., 2025)
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3. Research Methodology

This work uses a two-phase hybrid research method to identify and analyse issues associated with SCT. Using the one-round Fuzzy-Delphi method (FDM), the list of SCT challenges is identified from previous academic literature in the first phase of the study. The list of challenges is refined using industry expert judgments; these can provide emerging issues or unique challenges specific to the context of this study. The second phase then incorporates the AHP-entropy method to prioritize the identified challenges. The research methodology roadmap is shown in Figure 2.

To ensure reliable and contextually grounded insights, a panel of nine industry experts is engaged across both phases of the study - identification and prioritization of supply chain transparency (SCT) challenges. The selection of these experts follows a snowball sampling technique, wherein initial participants recommend additional qualified individuals within the field. This method ensures that all selected experts possess significant experience and relevance to the study context. Companies are shortlisted based on the following criteria: (a) Size of the company; (b) Sector (study focuses on manufacturing supply chain); (c) Implementing digital technologies into supply chains; (d) Domain knowledge (transparency, data and privacy issues, etc.)

Participants hold senior level positions such as Production Manager, Director, R&D Head, Design Head, or Technical Engineer across a range of industrial sectors including automotive manufacturing, machine tool manufacturing, food supply chain, agriculture products, textiles, and metal finishing equipment. All experts have extensive professional experience, ranging from 12 to 25 years, indicating a deep understanding of their respective domains. The same expert panel contributes to both phases of the research to maintain consistency in judgment and contextual alignment. In cases where some individuals cannot participate directly, they refer other domain-relevant professionals with comparable expertise and industry exposure.

For aggregation of expert judgments, the geometric mean method is applied to combine the individual pairwise comparison matrices into a single group comparison matrix. This approach preserves the reciprocal properties and ensures consistency in group decision-making. No significant outlier opinions are identified across experts, as reflected by the relatively consistent pairwise comparisons and low variability in derived weights. This indicates general agreement among participants regarding the prioritization of challenges.

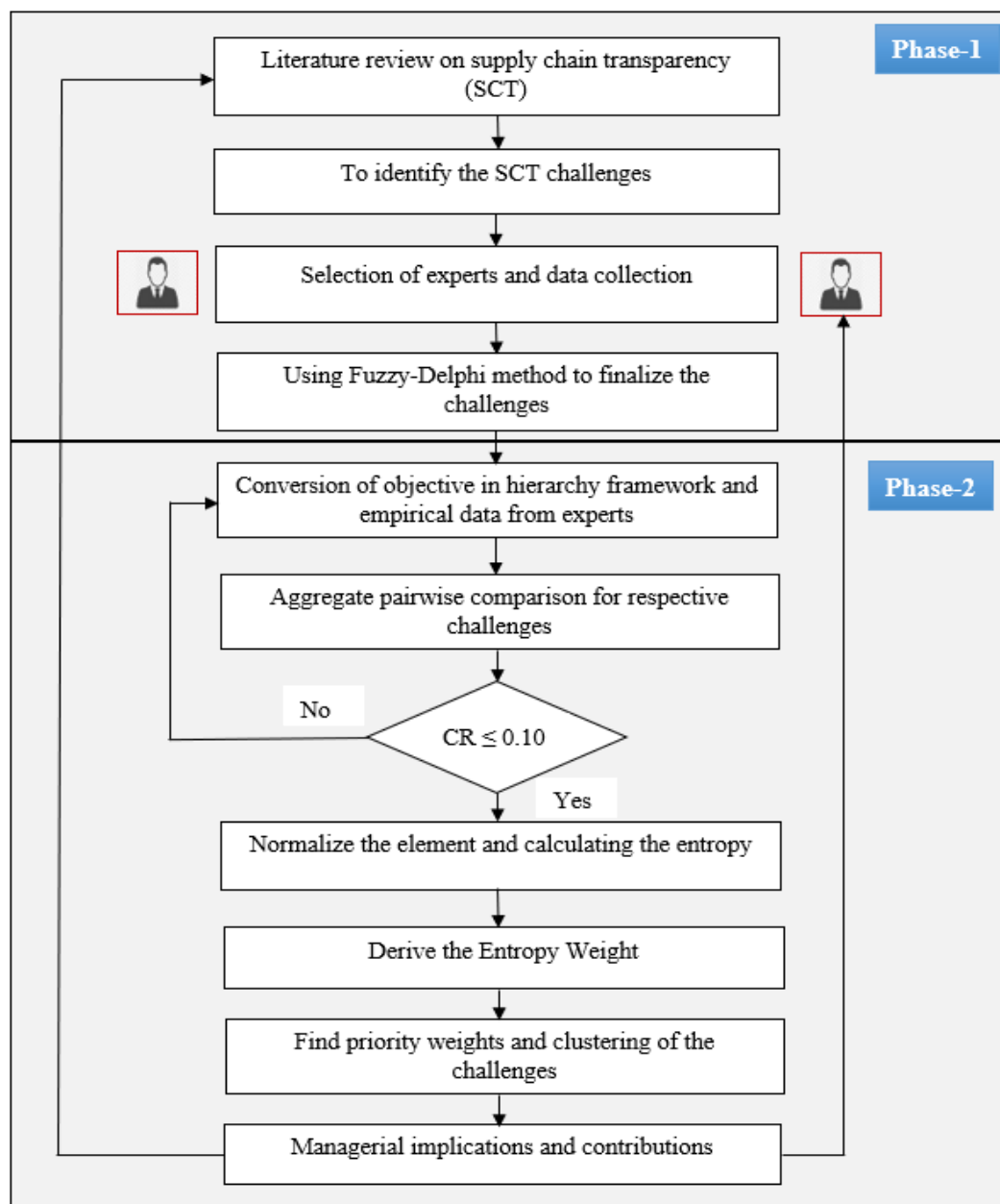


Figure 2: Research methodology flowchart

3.1 Phase 1: Fuzzy-Delphi method

The procedure that follows is based on the FDM and is used to gather and analyze the inputs from the nine experts. Fuzzy set theory was developed by Murray Thomas, who employed a blend of fuzzy theory analysis and the Delphi method in order to enhance the quality and efficiency of the conventional Delphi method surveys. FDM considers the circumstances in which humans cannot accurately define a judgment. The use of fuzzy theory prevents the distortion of each expert's opinion, obtains the semantic structure of the predicted objects, and considers the vagueness of the data obtained (Lee and Hsieh, 2016). Therefore, the FDM combination needs fewer samples and gives a better expression of expert knowledge (Ma et al., 2011). That is, FDM's strength lies in the basis that all experts' opinions are taken into consideration and combined with others to achieve consensus; this creates added value by reducing investigation time and decision-making expenses (Lee et al., 2018). For step-by-step procedures adopted for FDM, refer to Sonar et al. (2023).

We employ a 9-fuzzy scale in this research (Table 2); therefore, the threshold value for 9-fuzzy scale is 5.6, according to Zhang (2017). Table 4 indicates the set of challenges accepted and rejected based on the threshold value. It can be seen that three challenges with a lower threshold value ($\beta < 5.6$) are rejected and removed for further analysis. A challenge is only taken up for deeper analysis if its combined score across experts surpasses this cut point. This process guarantees that challenges are based not only on average consensus but also on the level of convergence in expert opinion, reducing outlier bias. Out of thirteen initial challenges, ten are retained with three excluded, based on this cutoff. The process thus ensures that the retained challenges reflect both expert agreement and perceived strategic importance. The detailed scoring and threshold values are presented in Table 3.

Table 2: Linguistic evaluation scale

Sr. No.	Linguistic parameter	Reference code	Numeric Scale
1	Absolute essential	AE	9
2	Very Important	VI	7
3	Important	I	5
4	Moderately Important	MI	3
5	Slightly important	SI	1

Table 3: Aggregate fuzzy Judgments

Challenges	Scores				
	Min	Max	Geometric Mean	Aggregate Fuzzy number	Final (defuzzification)
Cultural and Language Differences	3	9	6.944	3,9,6.944	6.3146
Lack of Technology Infrastructure	3	9	6.089	3,9,6.089	6.0296
Concerns with Competitive Advantage	3	9	6.421	3,9,6.421	6.1043
Suppliers Resistance	3	9	5.948	3,9,5.948	5.9826
Supply Chain Disruption Risk	1	9	4.228	1,9,4.228	4.7426
Complexity of Supply Chain	3	9	6.293	3,9,6.293	6.0976
Lack of Data Standardization	3	9	6.773	3,9,6.773	6.2576
Data Privacy and Security Issues	3	9	5.884	3,9,5.884	5.9613
Regulatory and legal Challenges	1	9	6.911	1,9,6.911	5.6370
High Cost and Time Consumption	1	9	4.115	1,9,4.115	4.7050
Unavailability of Skilled Resources	3	9	6.662	3,9,6.662	6.2206
Lack of Stakeholder Pressure	3	9	6.261	3,9,6.261	6.0871
Limited Accountability	1	9	4.464	1,9,4.464	4.8213

3.2 Phase 2: AHP-Entropy Method.

One of the well-known tools for multi-criteria decision-making (MCDM) is the Analytical Hierarchy Process (AHP) (Saaty, 2002). The Analytic Hierarchy Process (AHP) is chosen in this research because it permits structured decision-making through the use of industry expert opinion, specifically when ranking numerous qualitative issues. In contrast to the straightforward rating or ranking procedure, AHP permits pairwise comparison across all the issues, inviting experts to consider relative significance and not singular judgment. The process also provides a consistency ratio that enables researchers to check the internal reliability of the experts' inputs. Even though our model is not a multi-tiered hierarchy (i.e. all 10 challenges are at the same level), AHP is extensively applied for flat prioritization issues in operations and supply chain management when decision criteria are interdependent but not categorical (Roy et al., 2017; Kamaruzzaman et al., 2018). Thus, AHP offers a systematic and stringent approach for ranking SCT issues specific to digital businesses. Pairwise comparisons are utilized in AHP in order to establish priorities among the factors and sub-factors in a specific hierarchical level. This is supported by expert opinions with Saaty's nine-point scale. The AHP methodology is widespread in many fields, with priority assessment, importance weighting, and rating as its key uses (Roy et al., 2017; Kamaruzzaman et al., 2018).

However, AHP also has several flaws as a result of experts' arbitrary weighting judgments. The entropy technique, as used by Kamfiroozi and Bonyadi Naeini (2014) and Zhao *et al.* (2018), partially addresses these shortcomings. Thus, by overcoming the limitations of individual techniques, various studies (Chuansheng *et al.*, 2012; Zhao *et al.*, 2018) conclude that integrated AHP-Entropy could produce more realistic, accurate, and dependable results. The first recorded use of AHP-Entropy for decision-making in ship investments is reported by Zhong in 2000. In many applications, including weight assessment (Al-Aomar, 2010), safety evaluation (Chuansheng *et al.*, 2012), sustainability assessment (Wu *et al.*, 2017), and environment management (Bai *et al.*, 2018), the AHP-Entropy technique is widely employed. In addition, Yang and Lu (2024) use it to evaluate supplier transparency, while Bai *et al.* (2018) apply it to test the environmental management maturity model. In the housing community context, Wu *et al.* (2017) demonstrate its efficacy to evaluate community sustainability, while Freeman and Chen (2015) use it to assess green supplier selection.

To collect expert judgments for the AHP model, we develop a structured questionnaire featuring all pairwise comparisons required for the 10 SCT challenges. The questionnaire

follows Saaty's 9-point scale (Saaty, 2002), with anchors such as "1 = equal importance" and "9 = extremely more important." The survey is distributed and experts given a brief explanatory document containing: (1) Definitions of all SCT challenges; (2) Instructions on how to use the AHP scale; (3) A worked-out example of a sample pairwise comparison matrix; (4) A reminder about the need for consistency in judgments. Data is analyzed using Microsoft Excel and consistency ratios are calculated. The consistency ratio (CR) is computed for each expert's pairwise comparison matrix. All CR values are below the acceptable threshold of 0.1, indicating satisfactory consistency of judgments. Therefore, no revisions or exclusions of expert inputs are necessary. A sample of the questionnaire, including a pairwise comparison example, is provided in Appendix A to support reproducibility.

3.3 Steps of AHP-Entropy

The first step is aggregating pairwise comparison for factors. The experts are asked to assess pair-wise comparisons amongst factors using the nine-point intensity scale (Saaty, 2002). See Table 4.

Table 4: Saaty's nine-point intensity scale (Adopted from (Saaty, 2002))

Scale	Judgments of preferences
1	Equal importance
3	Moderate importance of one over the other
5	Essential or strong importance
7	Very strong or demonstrated importance
9	Extreme or absolute importance
2,4,6,8	Intermediate values between the two adjacent judgments

The weight entropy method is broken down into the following four steps.

(1) The ratio of index j is calculated first. It is derived from

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^n x_{ij}}$$

where p_{ij} is the level of the indicator i's contribution to the index j; x_{ij} represents the data of the j index of the i indicator.

(2) Next, determine the entropy value. It is calculated using.

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^n p_{ij} \cdot \ln p_{ij}$$

where e_j stands for the index j's degree of dispersion and is positively correlated to that index j's degree of dispersion.

(3) Thirdly, calculate the coefficient of difference. It can be expressed as

$$g_i = 1 - e_i$$

where g_i denotes the impact of the i index with respect to the research object.

(4) Finally, determine the weight. It can be calculated as:

$$w_i = \frac{g_i}{\sum_{i=1}^m g_i}$$

where w_i denotes an index's relative importance to other indexes (refer Table 7). The larger the w_i value is, the more significant the index is. Table 5 and Table 6 represent the aggregate relation matrix and normalized matrix respectively.

Table 5: Aggregate relation matrix

	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10
Cultural and Language Differences (Ch1)	1.000	4.000	5.000	2.000	2.000	0.250	0.200	0.500	2.000	2.000
Lack of Technology Infrastructure (Ch2)	0.250	1.000	0.333	0.250	5.000	0.167	6.000	4.000	4.000	4.000
Concerns with Competitive Advantage (Ch3)	0.200	3.000	1.000	6.000	0.333	0.333	0.333	0.250	0.250	2.000
Suppliers Resistance (Ch4)	0.500	4.000	0.167	1.000	5.000	0.333	5.000	3.000	3.000	3.000
Complexity of Supply Chain (Ch5)	0.500	0.200	3.000	0.200	1.000	0.167	3.000	0.167	3.000	0.333
Lack of Data Standardization (Ch6)	4.000	6.000	3.000	3.000	6.000	1.000	0.250	3.000	0.333	3.000
Data Privacy and Security Issues (Ch7)	5.000	0.167	3.000	0.200	0.333	4.000	1.000	4.000	6.000	6.000
Regulatory and legal Challenges (Ch8)	2.000	0.250	4.000	0.333	6.000	0.333	0.250	1.000	0.167	0.167
Unavailability of Skilled Resources (Ch9)	0.500	0.250	4.000	0.333	0.333	3.000	0.167	6.000	1.000	4.000
Lack of Stakeholder Pressure (Ch10)	0.500	0.250	0.500	0.333	3.000	0.333	0.167	6.000	0.250	1.000
Sum	14.450	19.117	24.000	13.650	29.000	9.917	16.367	27.917	20.000	25.500

Table 6: Normalized matrix

Challenges	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10
Ch1	0.069	0.209	0.208	0.147	0.069	0.025	0.012	0.018	0.100	0.078
Ch2	0.017	0.052	0.014	0.018	0.172	0.017	0.367	0.143	0.200	0.157
Ch3	0.014	0.157	0.042	0.440	0.011	0.034	0.020	0.009	0.013	0.078
Ch4	0.035	0.209	0.007	0.073	0.172	0.034	0.305	0.107	0.150	0.118
Ch5	0.035	0.010	0.125	0.015	0.034	0.017	0.183	0.006	0.150	0.013
Ch6	0.277	0.314	0.125	0.220	0.207	0.101	0.015	0.107	0.017	0.118
Ch7	0.346	0.009	0.125	0.015	0.011	0.403	0.061	0.143	0.300	0.235
Ch8	0.138	0.013	0.167	0.024	0.207	0.034	0.015	0.036	0.008	0.007
Ch9	0.035	0.013	0.167	0.024	0.011	0.303	0.010	0.215	0.050	0.157
Ch10	0.035	0.013	0.021	0.024	0.103	0.034	0.010	0.215	0.013	0.039

Table 7: Entropy weight matrix

Challenges	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10
Ch1	-0.185	-0.327	-0.327	-0.281	-0.184	-0.093	-0.054	-0.072	-0.230	-0.200
Ch2	-0.070	-0.154	-0.059	-0.073	-0.303	-0.069	-0.368	-0.278	-0.322	-0.291
Ch3	-0.059	-0.291	-0.132	-0.361	-0.051	-0.114	-0.079	-0.042	-0.055	-0.200
Ch4	-0.116	-0.327	-0.035	-0.191	-0.303	-0.114	-0.362	-0.240	-0.285	-0.252
Ch5	-0.116	-0.048	-0.260	-0.062	-0.116	-0.069	-0.311	-0.031	-0.285	-0.057
Ch6	-0.356	-0.364	-0.260	-0.333	-0.326	-0.231	-0.064	-0.240	-0.068	-0.252
Ch7	-0.367	-0.041	-0.260	-0.062	-0.051	-0.366	-0.171	-0.278	-0.361	-0.340
Ch8	-0.274	-0.057	-0.299	-0.091	-0.326	-0.114	-0.064	-0.119	-0.040	-0.033
Ch9	-0.116	-0.057	-0.299	-0.091	-0.051	-0.362	-0.047	-0.330	-0.150	-0.291
Ch10	-0.116	-0.057	-0.081	-0.091	-0.235	-0.114	-0.047	-0.330	-0.055	-0.127
Sum	-1.776	-1.722	-2.011	-1.636	-1.947	-1.646	-1.566	-1.961	-1.850	-2.041

Table 8: Ranking of challenges

Code	Challenges	ej	dj	Wj	Rank	Clusters
Ch7	Data Privacy and Security Issues	0.68020	0.31980	0.15124	1	Critical Digital Friction Points (Cluster 1)
Ch4	Suppliers Resistance	0.71055	0.28944	0.13688	2	
Ch6	Lack of Data Standardization	0.71466	0.28533	0.13494	3	
Ch2	Lack of Technology Infrastructure	0.74807	0.2519	0.11914	4	Operational Capability Gaps (Cluster 2)
Ch1	Cultural and Language Differences	0.77144	0.2285	0.10809	5	
Ch9	Unavailability of Skilled Resources	0.80342	0.19657	0.09296	6	
Ch5	Complexity of Supply Chain	0.84571	0.15428	0.07296	7	External and Strategic Constraints (Cluster 3)
Ch8	Regulatory and legal Challenges	0.85172	0.14827	0.07012	8	
Ch3	Concerns with Competitive Advantage	0.87328	0.12671	0.05992	9	
Ch10	Lack of Stakeholder Pressure	0.88640	0.1135	0.05372	10	

4. Results and Discussion

This work aims to prioritize a list of SCT challenges for digital enterprises. The AHP-entropy method is employed for this purpose. Inputs from industrial experts are collected for both the fuzzy-Delphi and AHP-entropy methods. The analysis confirms that all individual consistency ratios are within the acceptable limit of 0.1, demonstrating a high level of coherence in the experts' judgments. This outcome reinforces the reliability of the derived priority weights. To enhance interpretability and strategic actionability, the ranked SCT challenges are grouped into three clusters based on their importance weights. Cluster 1 - Critical Digital Friction Points comprises the top three challenges: *data privacy and security issues*, *supplier resistance*, and *lack of data standardization*. These challenges reflect the most immediate and fundamental barriers faced by digital enterprises and demand urgent attention due to their direct impact on information flow, trust, and collaboration across supply networks. Cluster 2 - Operational Capability Gaps includes issues such as *technological infrastructure deficits*, *cultural and language barriers*, and *shortage of skilled resources*, which, while slightly lower in priority, are nonetheless critical enablers of effective transparency. Lastly, Cluster 3 - External and Strategic Constraints covers broader systemic factors such as *regulatory ambiguities*, *competitive concerns*, and *low stakeholder pressure*. Although ranked lower, these challenges can significantly affect long-term strategy and ecosystem alignment. This clustering helps managers and policymakers to prioritize interventions sequentially, from core digital risks to ecosystem-level reforms.

Based on the weights obtained from the analysis, it is clear that “data privacy and security issues” are identified as the most important challenges for SCT, especially through digital transformation. Access to sensitive supply chain data must be strictly restricted to prevent data abuse or leakage resulting from unauthorized access by staff members, vendors, or other stakeholders. The three most important elements of security should be protected first when creating information security rules in a company - confidentiality, integrity, and availability (Morgan et al., 2023). Personal and sensitive information can be anonymized or de-identified prior to storage or disclosure to improve privacy. It is essential to audit the cybersecurity and data privacy procedures of the chosen suppliers or technology companies for SCT solutions to meet organizational standards (Berneis et al., 2024). A multi-pronged strategy with robust cybersecurity measures, adherence to relevant rules, continuous monitoring and assessment, and a commitment to ethical data practices is required to address these data privacy and security challenges. This finding underscores how the digitalization of supply chains

simultaneously expands transparency potential and amplifies cyber-vulnerabilities, confirming prior observations by both Saberi et al. (2019) and Berneis and Winkler (2024). The prioritization of this challenge suggests that firms perceive data security as a fundamental enabler for any credible transparency effort, rather than a separate compliance issue. To facilitate easier interpretation, we present the final prioritized challenges in graphical form. Figure 3 provides a corresponding bar chart that allows visual comparison of their relative importance.

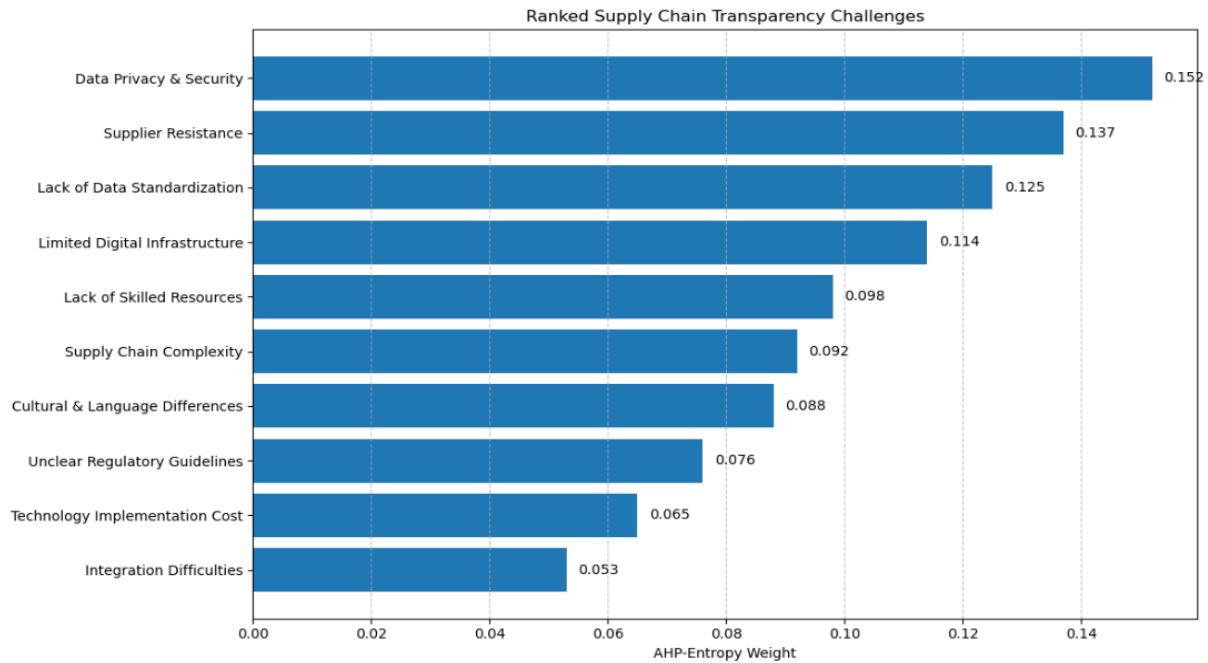


Figure 3: Ranking of SCT Challenges

Results show that “supplier resistance” is the second most critical challenge in forming a transparent supply chain. Suppliers may resist new transparency procedures or technology due to the typical human reaction of resistance to change. This is also in line with previously published work by both Kalesh et al. (2024) and Doorey (2011). Concerns may arise that sharing specific details about procedures, expenses, or suppliers could expose companies to competition or weaken their negotiating position. Some suppliers, especially smaller ones, may lack the tools, knowledge, or infrastructure required to participate in intricate transparency projects. Overcoming supplier resistance to transparency requires an inclusive and sympathetic approach. Assuring suppliers that transparency will increase their chances of success by promoting trust, enhancing teamwork, and developing a competitive edge through the creation of shared value is crucial. This result is consistent with Doorey (2011), who argues that transparency can initially be perceived by suppliers as a threat to bargaining power.

Interestingly, in this study, resistance is ranked second only to data security, highlighting that even in digitally mature firms, relational frictions remain a major obstacle to transparency adoption.

Lack of data standardization makes it difficult to achieve SCT, especially when dealing with cultural and language differences (Muratore and Marques, 2022). The consistent and efficient gathering, processing, and distribution of information throughout the supply chain network are severely hampered by a lack of data standardization. Patterns of communication, including information presentation and interpretation, can differ, often indicating underlying variations in culture. These issues are compounded by vocabulary, measuring, and data structure variations among supply chain partners. Format and protocol variability in data formats makes consolidating data from numerous sources difficult, limiting supply chain coordination and interoperability (Vazquez Melendez et al., 2024). In order to develop standard data formats, standards, and protocols, collaboration with supply chain partners is needed. By developing standardized data formats, communication protocols and best practices, industry associations and standardization organizations are in a position to speed up processes. Ultimately, these activities will lead to more robust and efficient supply chain operations by allowing interoperability, enhancing data consistency, and supporting coordination among all stakeholders in the supply chain. The prominence of data standardization challenges aligns with prior literature emphasizing interoperability as critical for end-to-end visibility (Queiroz & Wamba, 2019). The experts' emphasis on this issue suggests that even when organizations invest heavily in technology, common data frameworks remain a limiting factor to achieve seamless transparency.

The absence of technology infrastructure, lack of skilled resources, and supply chain complexities are also among the most critical issues for transparent supply chains. To enhance the connectivity and availability of key tools, it is vital to support investments in technology infrastructure at the regional and organizational levels (Faisal et al., 2023). Investment should be provided for training and skill development courses for existing personnel to enable them to gain the knowledge needed for transparency programs. Addressing challenges on transparency can also be tackled by developing cross-functional groups within a company, drawing from diverse disciplines to aggregate knowledge. Contemporary supply chains may have multiple participants, complex networks, and a number of processes, and as such, become highly complex. Advanced technology should be utilized to enhance visibility and traceability in these complex supply chains, including blockchain, Internet of Things (IoT), and data

analytics³. It should be understood that it may be a long-term goal to achieve total transparency in a supply chain. Transparency programs must be rolled out step by step, beginning with high-priority areas and subsequently expanding to additional areas.

The results clearly show that supplier resistance and data privacy are viewed as the most significant challenges. These results align with existing research (e.g. Morgan et al., 2023; Kalesh et al., 2024), which highlights the increasing complexity of transparency management in digitally interconnected ecosystems. Although these findings confirm previous studies, they also reflect how digital businesses are being confronted by a unique combination of privacy, compliance, and interoperability issues. In summary, the results address both research objectives. Regarding RO1 (identifying the major challenges for SCT), the AHP-Entropy results presented in Table 8 indicate that the most critical challenges are data privacy and security issues (priority weight = 0.151), supplier resistance (0.136), and lack of data standardization (0.135). Together, these top three challenges represent a substantial proportion of the overall importance, underscoring their significance in shaping transparency outcomes. Regarding RO2 (exploring how these challenges can be navigated), the study also gathers expert recommendations on potential strategies, such as strengthening data protection protocols, engaging suppliers through trust-building measures and incentive structures, and implementing standardized digital platforms to harmonize information sharing. These strategies are consistently emphasized across expert responses as critical to overcoming the identified challenges. Overall, these results provide a coherent understanding of both the key obstacles and the best avenues to address them in the context of digital supply chains.

To address these challenges, the solution lies in a multi-faceted approach that harnesses workforce development, investment in technology, stakeholder engagement, and a conscious effort to streamline complex supply chain functions. While not overnight solutions, transparent supply chains are within reach for organizations that apply the correct strategies consistently. Significantly, the intersection of technological deficits and human capability deficits underlines the significance of complementary strategies involving infrastructure upgrading and skill development. This conclusion reaffirms arguments by Rajput (2024) that multi-level interventions should be facilitated to support sustainable digital transparency.

³ <https://www.deloitte.com/us/en/services/consulting/articles/blockchain-supply-chain-innovation.html> (Accessed on 31st July 2025)

5. Implications

The remainder of the paper describes the primary implications of this research for scholars, practitioners, and general society. Through the identification of theoretical contributions and practical measures, these implications seek to shape future financial planning, inform managerial practice, and aid policy debate. Each perspective highlights how resolving transparency issues in digital supply chains can generate value and foster more sustainable and responsible business practices.

5.1 Implications for Research

This study can deliver significant theoretical contributions that enhance the body of academic knowledge in this complex domain. The study can help to evolve SCT theories, especially in the digital business environment. It can result in an improvement or formulation of existing theoretical models, assisting researchers to grasp the complex nature of transparency in the digital era. These research findings can shape ideas regarding the adoption and dissemination of digital technology, especially regarding campaigns for digital transparency. This can involve studying difficulties that affect the use of technology towards transparency, such as blockchain or IoT. Better knowledge about the influence of culture and cross-cultural issues on SCT could be one of the theoretical implications. For instance, the prominence of data privacy and interoperability issues indicates that future research could focus on developing and testing frameworks that integrate regulatory compliance with technological solutions to enhance transparency effectiveness.

Firstly, this paper enriches SCT theory by revealing how challenges to transparency change, when inserted in digitally altered organizations, hence bringing into view new antecedents (e.g. data interoperability, standardization concerns) and emergent barriers (e.g. technology-driven complexity, algorithmic obscurity) that traditional SCT approaches fail to highlight. Additionally, the relatively lower prioritization of supplier resistance in this study suggests a need to further explore under what contextual factors this challenge becomes more or less salient, as current literature often positions it as a universal barrier.

Secondly, the research provides a conceptual contribution to digital transformation scholarship by positioning SCT as simultaneously a driver and a result of digital capability construction. The research is in accordance with dynamic capabilities theory by demonstrating how companies construct adaptive capacities (e.g. cybersecurity infrastructure, supplier digital engagement) to meet transparency challenges. Lastly, with a hybrid AHP-Entropy prioritization, the article presents a structured methodology to assess SCT barriers more

accurately and therefore inject methodological rigor into digital SCM research as well as decision-making models. It broadens theoretical insight into the way subjective and objective views may be combined to study intricate digital systems in supply chains.

This research advances SCT research by not only affirming previously known challenges, but also exposing underdeveloped tensions specific to virtual businesses, such as digital resistance of the suppliers, data fragmentation, and immaturity of infrastructure, providing a prioritized roadmap to overcome these obstacles based on a hybrid decision-making perspective. The study can assist complexity theories that explain how supply chain networks develop and adapt in response to transparency initiatives, since contemporary supply chains are complex in nature. The study can explain how dynamic capabilities are embedded within digital organizations so that they can adapt to evolving transparency needs and technological advancements. Research on SCT issues in digital companies has the potential to enhance theoretical frameworks for supply chain management, technology adoption, data governance, and related fields. Theoretical implications pave the way for further research and better insight into the complex supply chain dynamics that need to become more transparent. Finally, as the study incorporates expert perspectives primarily from the manufacturing and technology sectors, future investigations should validate and extend these findings across other industries and regions to strengthen the generalizability of transparency-related theoretical models. Table 9 summarizes how this study contributes to theory by contrasting traditional views with new insights emerging from our findings. By reframing transparency as a dynamic capability, highlighting the frictional aspects of digital transformation, and emphasizing adaptive governance in interorganizational collaboration, this research advances conceptual understanding of SCT in a digitally enabled context. These contributions can inform future theoretical development and empirical studies in the field.

5.2 Implications for Practice

This study adds value through the use of a decision making support tool to establish a ranking of SCT challenges for digital businesses. Since most companies invest in digital transformation, this research assists practitioners in better comprehending the intricacy of SCT. This research facilitates an understanding of the significance of contemporary technological infrastructure in SCT. Transparency is the core characteristic of digital transformation to enhance visibility and information consolidation and drive cooperation between supply chain partners. Managers should prioritize investments in integrated information systems and secure supply chain data platforms to address data interoperability and fragmentation challenges; this

study identifies these as top-ranked barriers to transparency. Better SCT not only improves the operational efficiency of businesses but also meets escalating customer and regulatory requirements for moral and ethical supply chain practices. Practitioners should adopt a phased intervention strategy aligned with the identified clusters. Cluster 1 challenges, being the most critical, require immediate focus through investments in data security, standardization, and trust-building with suppliers. Once these digital friction points are addressed, attention should shift to Cluster 2, targeting capability enhancement and infrastructure gaps. Cluster 3 challenges, though less urgent, must not be overlooked, as resolving them supports long-term regulatory alignment and stakeholder engagement.

Table 9: Theoretical Implications of the Study

Theory Domain	Traditional View	New Insight from This Study	Theoretical Contribution
Supply Chain Transparency (SCT)	SCT is a static goal focused on information visibility across the supply chain.	In digital enterprises, SCT operates as a dynamic capability that evolves in response to technology and stakeholder demands.	Extends SCT theory by reframing transparency as an evolving organizational capability rather than a static design feature.
Digital Transformation	Digitalization inherently improves transparency, efficiency, and coordination.	Digitalization can also amplify complexity, supplier resistance, and data privacy risks.	Challenges techno-optimistic assumptions and calls for friction-aware models of digital transformation.
Interorganizational Collaboration	Emphasis on trust, alignment, and coordinated relationships among supply chain partners.	Transparency initiatives can expose asymmetric risks and perceived value differentials, leading to collaboration friction.	Refines collaboration theory by advocating adaptive governance approaches rather than purely coordination-based models.

This research can be used as a reference for organizations as they introduce digital platforms to increase the transparency of the supply chain. Understanding how social expectations, legal structures, and cultural norms affect practices of transparency can assist managers in making techniques more suitable for different geographic settings. Companies can enter into public-private partnerships to bridge gaps in the technology base in underserved communities. To reduce the skills gap, partnerships can be established with educational institutions and industry associations. Advanced technology can be leveraged to enhance SCT and traceability, e.g. blockchain, IoT, artificial intelligence (AI), and data analytics. For example, adopting blockchain-based traceability solutions can help ensure data immutability and enhance trust across supply chain partners, while advanced ERP systems can facilitate real-

time data sharing and reduce inconsistencies. These implications provide digital businesses with a blueprint for systematically addressing the challenges of SCT. Organizations can enhance SCT efforts, strengthen stakeholder relations, and derive competitive gains by implementing these strategies in today's globalized and interconnected world of business.

The need to integrate such technology into supply chain processes has become more important with the advent of Industry 4.0. Still, most companies struggle to integrate new technologies, especially in terms of how they affect human decision-making. While enhanced tracking and tracing of data can provide greater visibility, these developments can provide information that enhances SCT. Stakeholder theory can provide critical perspectives to study the benefits of technology adoption for internal as well as external stakeholders, empowering employee decision-making.

Our findings align with existing literature that identifies transparency as a persistent supply chain challenge (Saber et al., 2019). Whereas previous research highlights the potential for blockchain and IoT to drive SCT (Queiroz & Wamba, 2019), our findings add value by underscoring the synergistic impact of ambiguous regulatory environments, data interchangeability challenges, and digital enterprise resource limitations. This implies that although digital technologies have appealing solutions, their actual application impact on transparency depends on readiness at the ecosystem level and available institutional arrangements; this is an untapped area in existing state-of-the-art research.

Another key managerial consideration is managing supplier resistance to transparency efforts. Practitioners in this research highlight that suppliers might find data sharing a threat to their competitive edge or worry about the disclosure of confidential commercial data. To manage this hurdle, managers must actively involve suppliers in conversations to hear specific concerns and design data-sharing protocols together that accommodate the goals of transparency with confidentiality requirements. Drawing out clear contractual arrangements that identify what information will be exchanged, how it will be safeguarded, and the benefits of greater openness to both parties can assist in establishing confidence. Training courses and collaborative workshops can also clarify digital tools and alleviate fear. Additionally, providing benefits like preferred supplier status or extended contracts can encourage suppliers to join transparency schemes. Through a systematic, relationship-based approach, managers can enhance supplier acceptance and minimize resistance in the long run.

To establish supply chain risk and coordinate the efforts undertaken to increase transparency, risk assessments should be carried out on a frequent basis. It is necessary to ensure that transparency efforts are in line with applicable legal frameworks, such as data privacy and protection legislation. Effective preparations also enable policymakers to develop appropriate plans and formulate proper strategies to increase business digitalization for more transparent supply chains. Transparency programs must be rolled out step by step, starting with top-priority areas and incrementally moving to additional areas. Ultimately, as resource limitations are the norm, managers should adopt a phased approach to implementation, commencing pilot programs in targeted supply chain segments to prove value and develop organizational acceptance before expanding transparency programs company wide.

5.3 Implications for Society/Policy

Increasing SCT has far-reaching implications for society, including ethical sourcing, labour rights, and environmental sustainability. As the business sector is called upon to be more accountable by civil society and consumers alike, addressing the challenges enumerated in this research, including data fragmentation, regulatory uncertainty, and technological gaps, can assist in ensuring that supply chains are more transparent. Transparency facilitates improved traceability of products and practices, lowering the likelihood of exploitation, greenwashing, or unethical sourcing. Therefore, by foregrounding and putting emphasis on such obstacles, this study contributes to an informed path towards responsible business conduct that can embrace broader societal expectations.

Policy-wise, the research findings emphasize that governments and regulatory agencies should facilitate transparency efforts through straightforward, harmonized guidelines and infrastructure assistance. For example, the highest-ranked problem of regulatory uncertainty implies that inconsistent or vague reporting requirements can deter companies from adopting full transparency. Policymakers may counter this by establishing sectoral data governance models, a minimum disclosure regime, and incentives for the uptake of digital traceability (e.g. tax credits or compliance credits). Public investment in common digital platforms or e-governance portals for reporting supply chain data can minimize the adoption hurdle, especially for small and medium enterprises.

At the organizational level, firms should consider aligning their internal policies with global transparency and sustainability standards, such as GRI or ISO guidelines. Creating internal governance mechanisms, such as cross-functional transparency task forces or ethical

sourcing committees, can drive accountability and consistency. Furthermore, multi-stakeholder collaboration among firms, NGOs, industry consortia, and government agencies can lead to the co-creation of sector-wide data-sharing protocols and trust frameworks. The results of this study suggest that tackling transparency challenges is not just a technical or managerial issue, it requires coordinated policy efforts across public and private actors to generate system-level impact.

6. Conclusion

The main objective of this research is to rank the significant issues of SCT for digital businesses. Thirteen issues are identified from previous academic literature and confirmed using the fuzzy-Delphi method. The final list of ten issues is then utilized for further analysis using the AHP-Entropy method for ranking. Data is collected from nine supply chain professionals. The findings indicate that data security and privacy concerns are the most significant issues for SCT in digital businesses. This is followed by resistance from suppliers to new transparent processes, digital infrastructure, and technologies. However, it is important to note that these findings are based on expert judgments primarily drawn from the manufacturing and technology sectors in India, and therefore, the conclusions should be interpreted in this context rather than generalized across all industries or geographies without further validation. In summary, through collecting, sharing, and analyzing data from throughout the supply chain ecosystem, digital organizations can enhance transparency in supply chain operations. This study opens a focused debate on supply chain transparency in digital enterprises, identifies and prioritizes practical SCT challenges, and offers new theoretical insights by contrasting traditional views with findings from a digitally enabled context. The research findings have been discussed with the experts, and no further improvements were suggested. The recommendations outlined in this study, including investments in data governance frameworks, capacity building, and supplier engagement initiatives, are synthesized from the strategies suggested by the participating experts during the AHP evaluation process. To navigate the above challenges, firms may consider adopting multi-level strategies such as establishing clear regulatory compliance protocols, leveraging blockchain for secure information sharing, investing in interoperable data platforms, and designing incentive structures to reduce supplier resistance. These approaches are consistently highlighted by experts as critical to enabling effective transparency practices.

However, this work has a few limitations. It includes nine experts in developing the AHP relationship matrix; additional experts can provide different perspectives on challenges for SCT. Operations Research (OR) scholars may validate the findings using other techniques, such as the best-worst method, DEMATEL, structural equation modeling, etc. Additionally, to generalize the results, specialists from various regions could also be taken into account. Researchers could explore the impact of emerging technologies on SCT and how these technologies can enhance data privacy, security, and real-time tracking within digital enterprises. Future research may also explore the integration of environmental, social and governance (ESG) factors into transparent supply chains. For digital enterprises, the future of SCT is intimately correlated with technological improvements, changing consumer expectations, changing regulatory landscapes, and the dynamics of the global supply chain. It can assist digital enterprises in navigating the benefits and difficulties of a more open and connected world by offering insightful information to both academia and business. Instead of mere validation of known issues, this research provides a systematic ranking of SCT barriers, offering digital businesses an actionable set of risks categorized according to expert consensus. The combination of AHP and entropy contributes increased robustness and objectivity, presenting methodologically unique and practically focused contributions to SCT studies.

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