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Fostering Supply Chain Flexibility Under Economic Uncertainty: Role of Digitalization, Collaboration, Visibility, and Risk Management

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ABSTRACT

Today, turbulence in the economic environment creates numerous challenges across various aspects of firms, requiring organizations to respond quickly to survive and grow. As a result, supply chain flexibility (SCF) has become a strategic priority for companies and a prevalent topic in academia. Grounded in Resource-Based View (RBV) and Dynamic Capabilities Theory (DCT), this study examines how the business environment (ENVI) drives digitalization in operations management activities (DOM) and how DOM enhances SCF both directly and indirectly through supply chain visibility (SCV), supply chain collaboration (SCC), and supply chain risk management (SCRM). In this research, we collected data from 289 Vietnamese firms and analyzed them using PLS-SEM. We checked the reliability and discriminant validity of the measurement scales, then predicted the effect sizes and mediation effects of the relationships. The results show that ENVI significantly drives DOM adoption, which in turn improves SCV, SCC, and SCRM, thereby strengthening SCF. The findings reveal that supply chain visibility and risk management, but not collaboration, mediate the DOM–SCF relationship and function as sequential pathways through which environmental turbulence translates into greater supply chain flexibility. Furthermore, the research offers managerial insights into leveraging digital tools to construct more adaptable and resilient supply chains in volatile economic environments.

1. Introduction

The contemporary business landscape is increasingly characterized by volatility, uncertainty, complexity, and ambiguity (VUCA). External disruptions such as geopolitical crises, pandemics, and rapid technological shifts have exposed structural vulnerabilities in supply chains, elevating resilience and flexibility from operational concerns to strategic imperatives [1, 2]. In response, companies must continuously sense environmental changes, reconfigure resources, redesign operational models, and adopt various managerial and digital solutions to strengthen their supply chain flexibility [3].

Supply chain flexibility (SCF), the capability to rapidly adapt to market fluctuations and changing customer demands while maintaining operational continuity, is widely recognized as a key enabler

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of supply chain resilience [4]. Numerous studies have highlighted SCF's critical role in improving supply chain performance and overall business outcomes. Specifically, the flexibility in sourcing and logistics not only directly enhances firm-level performance but also mediates the relationship between customer/supplier integration and supply chain performance [5].

Given its strategic importance, numerous studies have sought to identify the key enablers of SCF. Nguyen Thanh Thuy [6] identified six critical factors influencing SCF, including leadership commitment, supply chain strategy, IT-enabled information sharing, supplier relationships, workforce flexibility, and production and logistics infrastructure. The application of digital technologies in operations is increasingly recognized as a strategic lever for developing adaptive capabilities, enabling firms to enhance data-driven decision-making, improve operational responsiveness, and better navigate environmental turbulence [3]. Indeed, the digitalization of operations management (DOM) has emerged as a crucial determinant of SCF [7–9]. However, digital transformation alone does not automatically translate into greater SCF; rather, its impact is realized through the development of intermediate supply chain capabilities such as supply chain risk management (SCRM), supply chain visibility (SCV), and supply chain collaboration (SCC) [9, 10].

Despite growing recognition of these relationships, limited research has examined the complex relationships among ENVI, DOM, and SCF, as well as the single- and serial-mediating roles of SCC, SCV, and SCRM. To address this research gap, this study aims to examine how ENVI and DOM enhance SCF and contribute to greater adaptability and responsiveness in increasingly volatile business environments, through the following research questions:

- How does the turbulent business environment shape a firm's digitalization of operations management and supply chain flexibility?
- Through what supply chain capabilities does the firm's digitalization of operations management enhance supply chain flexibility?

Drawing on the Technology–Organization–Environment framework [11] and Dynamic Capabilities Theory [12], this study examines how firms respond to environmental turbulence through digital transformation and subsequently develop supply chain flexibility. As uncertainty intensifies, firms increasingly invest in digital technologies and relational mechanisms that strengthen risk anticipation, enhance coordination, and support adaptive responses to disruptions.

This study contributes to the literature in several important ways. First, we reposition the digitalization of operations as a digitally enabled dynamic capability that underpins the development of higher-order supply chain capabilities. We then develop a multi-layer mediation model to unpack the mechanisms through which visibility, collaboration, and risk management translate digital investments into greater flexibility. Finally, we demonstrate how environmental turbulence shapes capability-building processes within supply chains, extending the dynamic capability perspective into digitally intensive operational contexts.

Our research offers several important implications for managers operating in turbulent environments. Rather than viewing digitalization as a purely technological investment, firms should approach it as a strategic enabler of capability development. By strengthening supply chain visibility, fostering closer collaboration with partners, and institutionalizing proactive risk management practices, organizations can translate digital investments into greater operational flexibility. This capability is particularly critical for anticipating disruptions, responding rapidly to market changes, and maintaining continuity under uncertainty. Managers are therefore encouraged to align digital transformation initiatives with broader supply chain strategies to ensure that technology adoption drives adaptive, resilient operations rather than isolated efficiency gains.

The structure of the paper is as follows. Section 2 develops the theoretical background and hypotheses. Section 3 outlines the research methodology. Section 4 presents the research results.

Section 5 discusses the findings. Section 6 concludes the study by summarizing its contributions and outlining future research directions.

2. Literature Review and Hypothesis Development

2.1 Supply Chain Flexibility

Supply chain flexibility (SCF) has been widely recognized as a critical capability that enables firms to adapt quickly and effectively to unexpected changes in demand, supply disruptions, or market turbulence without compromising performance [13]. Building on this view, subsequent studies highlight that the essence of SCF lies in its ability to rapidly adjust resilience strategies and processes, thereby strengthening organizational resilience in the face of uncertainty [14, 15]. Beyond operational adjustments, the flexibility of information systems has also been recognized as an important enabler, supporting real-time decision-making and fostering long-term supply chain sustainability [16, 17]. According to Bozanic *et al.*, [18], amid rapidly changing global conditions, the capacity to dynamically adapt and update assessments in real time is of paramount importance. Scholars generally agree that SCF not only safeguards operational continuity but also improves business performance and long-term viability, with its key components including sourcing, production, logistics, information technology, supplier partnerships, and supply chain strategy [13, 17, 19]. Therefore, identifying and analyzing the factors that influence SCF is crucial for managers to develop effective strategies that facilitate adaptive responses to current challenges while enhancing enduring competitiveness in a volatile market [20].

2.2 Digitalization of Operations Management

Recent studies interpret Digitalization of Operations Management (DOM) as a multidimensional concept from various perspectives. Reis and Melão [21] described digitalization as more than just data digitization, emphasizing its role in transforming how organizations operate and create value through technologies such as AI, sensors, and robotics. Emon and Khan [22] viewed DOM as part of the second digital revolution, in which control and management systems are restructured based on big data and continuous connectivity. Meanwhile, Gupta [23] defined DOM as the integration of digital technologies into financial management, operational processes, and organizational structures to improve productivity and develop new business models. The implementation of DOM brings numerous benefits, including enhanced transparency and visibility in operations, improved flexibility and responsiveness, and overall better performance in manufacturing firms [24]. Furthermore, by leveraging data analytics and connected platforms, organizations can optimize decision-making, reduce operational costs, and adapt more effectively to market fluctuations [23].

Regarding the relationship between DOM and SCF, previous studies have argued that digitalization can support supply chain flexibility by improving integration, connectivity, and visibility [25, 26]. However, most research has focused on Industry 4.0, smart supply chains, or digital transformation in general, rather than directly examining the role of DOM in enhancing SCF. This creates a research gap in understanding the specific impact of DOM on SCF, including both direct and indirect effects. Therefore, this study aims to explore how dynamic business environments drive supply chain flexibility (SCF) through the digitalization of operations management (DOM) and the development of key supply chain capabilities, including supply chain collaboration (SCC), supply chain visibility (SCV), and supply chain risk management (SCRM).

2.3 Business Environment as a Driver of DOM and Supply Chain Flexibility

Grounded in the Technology–Organization–Environment (TOE) framework [11], business environmental turbulence is a critical environmental driver that shapes firms' technology adoption

decisions. When the business environment changes rapidly and becomes highly unpredictable, companies are motivated to adopt digital technology such as big data, IoT, and automation to enhance their operations and resilience [22, 27]. So, instead of being merely a problem, environmental turbulence can act as a key driver of digitalization adoption in operations management across a wide range of enterprises and for strengthening supply chain flexibility. Therefore, this study proposes the following hypotheses:

H1: Business Environmental Turbulence (ENVI) positively influences the adoption of Digital technologies in Operations Management (DOM).

H2: Business Environmental Turbulence (ENVI) positively influences Supply Chain Flexibility (SCF).

2.4 Role of Digitalization of Operations Management in Fostering Supply Chain Flexibility through Supply Chain Collaboration, Visibility, and Risk Management

The role of DOM has become increasingly important in reshaping modern supply chains. Specifically, prior studies show that DOM plays a vital role in enhancing supply chain collaboration by improving information sharing, joint decision-making, and co-creation for innovation [28–31]. In addition, digital technologies such as IoT, Big Data, AI, and Blockchain enable data digitization, transparency, real-time monitoring, and business continuity, thereby strengthening both supply chain visibility and supply chain flexibility [32, 33]. Furthermore, given that risk assessment is a highly complex task [34, 35] and risk management is inherently challenging, DOM contributes to effective supply chain risk management by enabling real-time risk evaluation, mitigating cybersecurity threats, supporting risk prediction, and facilitating collaboration to reduce ripple effects [36, 37]. Therefore, in this research, we investigate the impact of DOM on four key supply chain management dimensions, including supply chain collaboration (SCC), supply chain visibility (SCV), supply chain risk management (SCRM), and critically, supply chain flexibility (SCF). Based on these insights, the following hypotheses are proposed:

H3a: Digitalization of Operations Management (DOM) positively influences Supply Chain Visibility (SCV).

H3b: Digitalization of Operations Management (DOM) positively influences Supply Chain Collaboration (SCC).

H3c: Digitalization of Operations Management (DOM) positively influences Supply Chain Risk Management (SCRM).

H3d: Digitalization of Operations Management (DOM) positively influences Supply Chain Flexibility (SCF).

Supply chain visibility (SCV) refers to the extent to which firms can monitor, track, and access timely information about material, product, and information flows across the supply chain [38, 39]. Enhanced visibility enables firms to acquire real-time external information and detect environmental fluctuations [40] as well as potential supply disruptions earlier, thereby enabling timely adjustments such as reallocating inventory, rerouting shipments, or rescheduling production [41]. Prior studies have suggested that visibility reduces uncertainty and the bullwhip effect, while also supporting rapid decision-making [42, 43]. Furthermore, when companies gain greater transparency into supply chain operations, they can respond more quickly and effectively to changes, thereby strengthening their overall flexibility [44]. Therefore, in the context of Vietnam, we aim to empirically examine the relationship between SCV and SCF as follows:

H4a: Supply Chain Visibility (SCV) positively influences Supply Chain Flexibility (SCF).

According to [45], supply chain collaboration (SCC) is defined as a long-term relationship in which firms share information, jointly plan, and coordinate the execution of supply chain activities. Previous research has highlighted that close collaboration among supply chain members not only enhances

operational performance but also serves as an external knowledge source and a supportive resource, enabling firms and their partners to exchange information in a timely manner to cope with shocks in the business environment [3, 46-49]. In addition, Baah *et al.*, [44] and Kumar [45] demonstrated that collaboration in the supply chain strengthens a firm’s ability to sense changes in the market and to respond quickly to fluctuations in customer demand. As a result, we believe that collaboration among supply chain members significantly enhances supply chain flexibility in an increasingly turbulent environment.

H4b: Supply Chain Collaboration (SCC) positively influences Supply Chain Flexibility (SCF).

Supply chain risk management (SCRM) involves identifying, assessing, and monitoring risks in supply chain operations [50]. Through core practices such as contingency planning, contractual risk-sharing, and business continuity planning, SCRM helps firms reduce vulnerability to disruptions and reconfigure material flows and processes promptly [51, 52]. In today’s volatile economic environment, flexibility in supply and production mitigates supply and production-process risks; accordingly, effective risk management is a key antecedent of supply chain flexibility [53]. In this research, we propose the following hypothesis to examine the impact of SCRM on SCF.

H4c: Supply Chain Risk Management (SCRM) positively influences Supply Chain Flexibility (SCF).

2.5 Mediation Effects of Digitalization and Supply Chain Dynamic Capability

Anchored in the dynamic capabilities theory and TOE framework, the digitalization of operations management not only directly enhances supply chain flexibility but also mediates the relationship between the turbulent business environment and SCF (Figure 1). These relationships operate through the development of intermediary supply chain capabilities, including collaboration, visibility, and risk management [52, 54]. Indeed, operational digitalization—through the adoption of management software and Industry 4.0 technologies such as IoT, big data analytics, blockchain, and AI—enables firms to collect and process real-time data, thereby improving overall supply chain visibility, promoting closer collaboration among supply chain members, and enhancing risk forecasting and mitigation [54–56].

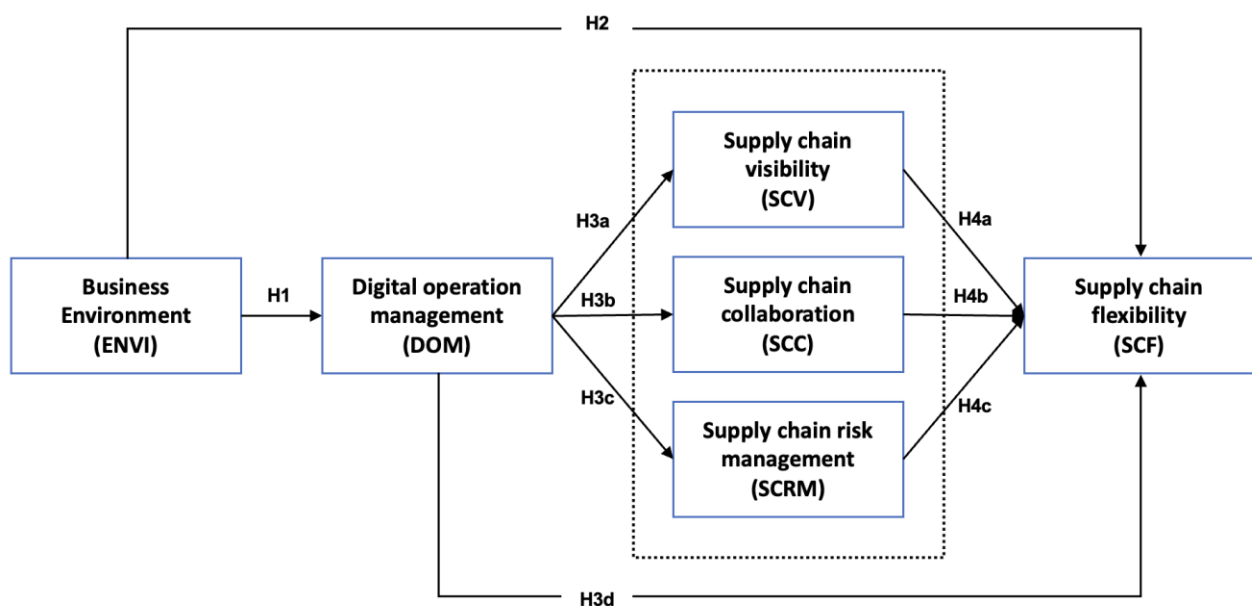


Fig.1. Research model

Collectively, these capabilities allow firms to sense disruptions, seize emerging opportunities, and reconfigure operational resources. Therefore, we empirically examine the mediating roles as follows:

H5: Digitalization of Operations Management (DOM) mediates the relationship between the Business Environment (ENVI) and Supply Chain Flexibility (SCF).

H6a: Supply Chain Visibility (SCV) mediates the relationship between Digitalization of Operations Management (DOM) and Supply Chain Flexibility (SCF).

H6b: Supply Chain Collaboration (SCC) mediates the relationship between Digitalization of Operations Management (DOM) and Supply Chain Flexibility (SCF).

H6c: Supply Chain Risk Management (SCRM) mediates the relationship between Digitalization of Operations Management (DOM) and Supply Chain Flexibility (SCF).

H7: Digitalization of Operations Management (DOM) and supply chain dynamic capabilities (SCV, SCC, SCRM) sequentially mediate the relationship between the Business Environment (ENVI) and Supply Chain Flexibility (SCF).

3. Research Methodology

3.1 Measurements of Variables and Data Collection

To investigate how the DOM and key supply chain capabilities (collaboration, visibility, and risk management) enhance supply chain flexibility under environmental turbulence, this study utilized a questionnaire-based survey and applied partial least squares structural equation modeling (PLS-SEM) for data analysis. The questionnaire consisted of three main sections. The first section gathered general information about the businesses, including company age, number of employees, the geographical scope of primary markets and suppliers, and business area. The second section assessed the extent of digitalization in operations management processes using a five-point scale from 1 (not yet adopted) to 5 (widely adopted across the supply chain), adapted from previous studies [57, 58]. The final section evaluated the dependent variable (SCF), mediating variables (SCC, SCV, and SCRM), and the independent variable (ENVI) using a five-point Likert scale, where 1 = strongly disagree, 3 = neutral, and 5 = strongly agree [59–61].

The questionnaire was initially distributed via email to a wide range of companies in Vietnam's northern region via the databases of industrial park management boards and tax offices. We subsequently contacted companies' representatives by phone to arrange online interviews with two to three managerial representatives. From September 2024 to May 2025, 289 companies agreed to participate in interviews lasting approximately 60–90 minutes to complete the survey.

Table 1 presents the general characteristics of the surveyed firms. Regarding firm age, 62% of the companies have been operating for at least 15 years, while 38% are younger firms with less than 15 years of experience, indicating a sample that includes both established and relatively young enterprises. In terms of firm size, 54% of firms employ fewer than 200 employees, whereas 46% employ 200 or more, suggesting a balanced representation of small- and medium-sized enterprises (SMEs) alongside larger firms. Regarding market orientation, a substantial proportion of firms demonstrate strong international engagement. On the demand side, 72% of the surveyed firms report engaging in global sales activities, while 80% on the supply side are involved in global sourcing.

Regarding the business sectors, the majority of respondents operate in electronic components and equipment manufacturing (35.6%), followed by fabricated metal products and mechanical engineering (30.1%), and automotive and motorcycle manufacturing and supporting industries (15.6%). The food and beverage processing sector accounts for 10.4% of the sample, while textiles and apparel account for 5.2%. The remaining firms are distributed across chemicals and pharmaceuticals, plastics manufacturing, industrial machinery, and other activities.

Table 1
General information of the surveyed companies

Category	Characteristics	Percentage	Business Sectors	Percentage
Company age	< 15 years	38	Electronic components and equipment	35.6
	>= 15 years	62	Metal products and mechanical engineering	30.1
Number of employees	< 200	54	Automotive, motorcycle, and supporting	15.6
	>= 200	46	Food and beverage processing	10.4
Demand side	Global sales	72	Textiles and apparel	5.2
Supply side	Global sourcing	80	Others	3.1

3.2 Data Analysis

In this research, we employed Partial Least Squares Structural Equation Modeling (PLS-SEM) to test the proposed research hypotheses, as it is well-suited for prediction-oriented research, robust in handling small to medium sample sizes, and appropriate for data that may not follow a normal distribution [62]. The collected data were analyzed using SmartPLS 4 software, which is particularly suitable for estimating complex models with multiple mediating relationships and predictive objectives [63]. Following the two-step approach recommended for PLS-SEM, the measurement model was first assessed to ensure the reliability and validity of the reflective constructs. The results presented in Section 4.1 indicate that the measurement model satisfies the recommended criteria for reliability and validity, thereby supporting the appropriateness of using PLS-SEM for subsequent structural model analysis.

4. Research Results

4.1 Validity and Reliability of the Measurement Model

To ensure the validity of the measurement model, the study assessed convergent validity through indicators such as outer loadings, Cronbach's Alpha (CA), composite reliability (CR), and average variance extracted (AVE). The results in Table 2 indicate that all item loadings exceeded 0.70. At the same time, Cronbach's Alpha exceeded the threshold of 0.80 [64]. Moreover, the CRs for all constructs were above 0.848, further strengthening the reliability evidence [62]. AVE values ranged from 0.693 to 0.777, which are above the threshold of 0.50, indicating that the constructs explain a substantial proportion of the variance in the observed variables [65]. Overall, these results confirm the reliability of the measurement scales and provide a solid foundation for further structural model analysis.

The discriminant validity was further assessed to confirm that the research concepts were empirically distinct. According to Table 3, all Heterotrait-Monotrait (HTMT) ratios are below the recommended conservative threshold of 0.85, indicating satisfactory discriminant validity [66]. Overall, the results from Tables 2 and 3 confirm that the measurement model meets all the required criteria for reliability, convergent validity, and discriminant validity, thereby providing a solid foundation for the subsequent structural model analysis.

Table 2
Measurement model results

Construct	Item	Item's Name	Loading
Digitalization of Operations Management <i>CA:0.934</i> <i>CR:0.934</i> <i>AVE:0.716</i>	DOM1	The extent to which our company applies descriptive analytics (e.g., dashboards, Tableau, PowerBI) in operations management	0.786
	DOM2	The extent to which our company applies predictive analytics (e.g., demand forecasting, risk prediction) in operations management	0.893
	DOM3	The extent to which our company applies prescriptive analytics (e.g., operational optimization) in operations management	0.859
	DOM4	The extent to which our company utilizes big data analytics technologies and platforms (e.g., SAS Enterprise Miner, Apache Hadoop)	0.874
	DOM5	The extent to which our company applies blockchain technology (e.g., smart contracts) in operations management	0.811
	DOM6	The extent to which our company deploys artificial intelligence (AI) models in operations management.	0.880
	DOM7	The extent to which our company uses Internet of Things (IoT) technologies for data collection and real-time operational connectivity.	0.817
Business Environment <i>CA:0.838</i> <i>CR:0.848</i> <i>AVE:0.755</i>	ENVI1	Our business environment is highly uncertain	0.870
	ENVI2	Our business environment is complex, with many factors affecting decision-making.	0.851
	ENVI3	Technologies relevant to our operations evolve rapidly.	0.885
Supply Chain Collaboration <i>CA:0.921</i> <i>CR:0.922</i> <i>AVE:0.760</i>	SCC1	Our company collaborates closely with supply chain partners in developing strategic plans	0.821
	SCC2	Our company works jointly with supply chain partners to respond to environmental disruptions	0.894
	SCC3	Supply chain partners proactively share critical information with our company	0.885
	SCC4	Supply chain partners support us in managing risks and operational difficulties	0.887
	SCC5	Our company maintains long-term cooperative relationships with supply chain partners	0.868
Supply Chain Flexibility <i>CA:0.911</i> <i>CR:0.912</i> <i>AVE:0.693</i>	SCF1	Our supply chain can rapidly adjust capacity in response to market uncertainties	0.832
	SCF2	Our supply chain can modify product or service offerings to accommodate market changes	0.841
	SCF3	Our supply chain is flexible in selecting delivery modes	0.827
	SCF4	Our supply chain can adjust order quantities to mitigate disruptions	0.861
	SCF5	Our supply chain can modify supplier delivery lead times when disruptions occur	0.828
	SCF6	Our supply chain can reschedule deliveries quickly in response to unexpected events	0.804
Supply Chain Risk Management <i>CA:0.886</i> <i>CR:0.893</i> <i>AVE:0.746</i>	SCRM1	Our company systematically identifies potential risks across the supply chain (supply side, demand side, operations, business environment)	0.796
	SCRM2	Our company systematically evaluates the probability and potential losses of supply chain risks	0.888
	SCRM3	Our company implements effective mitigation strategies for supply chain risks	0.875
	SCRM4	Our company continuously integrates supply chain risk management into operation management	0.892
Supply Chain Visibility <i>CA:0.857</i> <i>CR:0.858</i> <i>AVE:0.777</i>	SCV1	Inventory information is transparent across our supply chain	0.867
	SCV2	Customer demand information is visible across our supply chain	0.885
	SCV3	Order-related information is accessible to relevant supply chain partners in real time	0.893

Table 3
 Heterotrait–Monotrait ratio (HTMT)

Variables	DOM	ENVI	SCC	SCF	SCRM	SCV
DOM	-					
ENVI	0.236	-				
SCC	0.467	0.420	-			
SCF	0.439	0.482	0.573	-		
SCRM	0.435	0.271	0.666	0.645	-	
SCV	0.393	0.458	0.595	0.711	0.600	-

4.2 Structural Model

The structural model in Figure 2 and Table 4 indicates that eight out of the nine research hypotheses (H1- H4c) are supported at p-values < 0.05 [62], except for H4b. Specifically, ENVI has a positive and statistically significant relationship with DOM ($\beta = 0.213$, $t = 4.132$, $p = 0.000$), indicating that the external environment has a moderate impact on promoting enterprise digital transformation. In addition, DOM has a direct and significant impact on SCC ($\beta = 0.435$, $p < 0.001$), SCV ($\beta = 0.353$, $p < 0.001$), and SCRM ($\beta = 0.397$, $p < 0.001$), confirming the central role of digital operations management in enhancing collaboration, improving visibility, and managing supply chain risks. For hypothesis group H4, the results also show that only two out of three relationships are statistically significant. Specifically, SCV affects SCF with $\beta = 0.34$, $t = 5.867$, and $p < 0.001$; SCRM affects SCF with $\beta = 0.28$, $t = 4.226$, and $p < 0.001$; while SCC has the weakest impact with $\beta = 0.064$, $t = 1.003$, and $p > 0.05$ (p value = 0.316). Thus, hypotheses H4a and H4c are supported, whereas H4b is not, indicating that there is no relationship between SCC and SCF. The results emphasize that supply chain risk management is a key factor in enhancing supply chain flexibility.

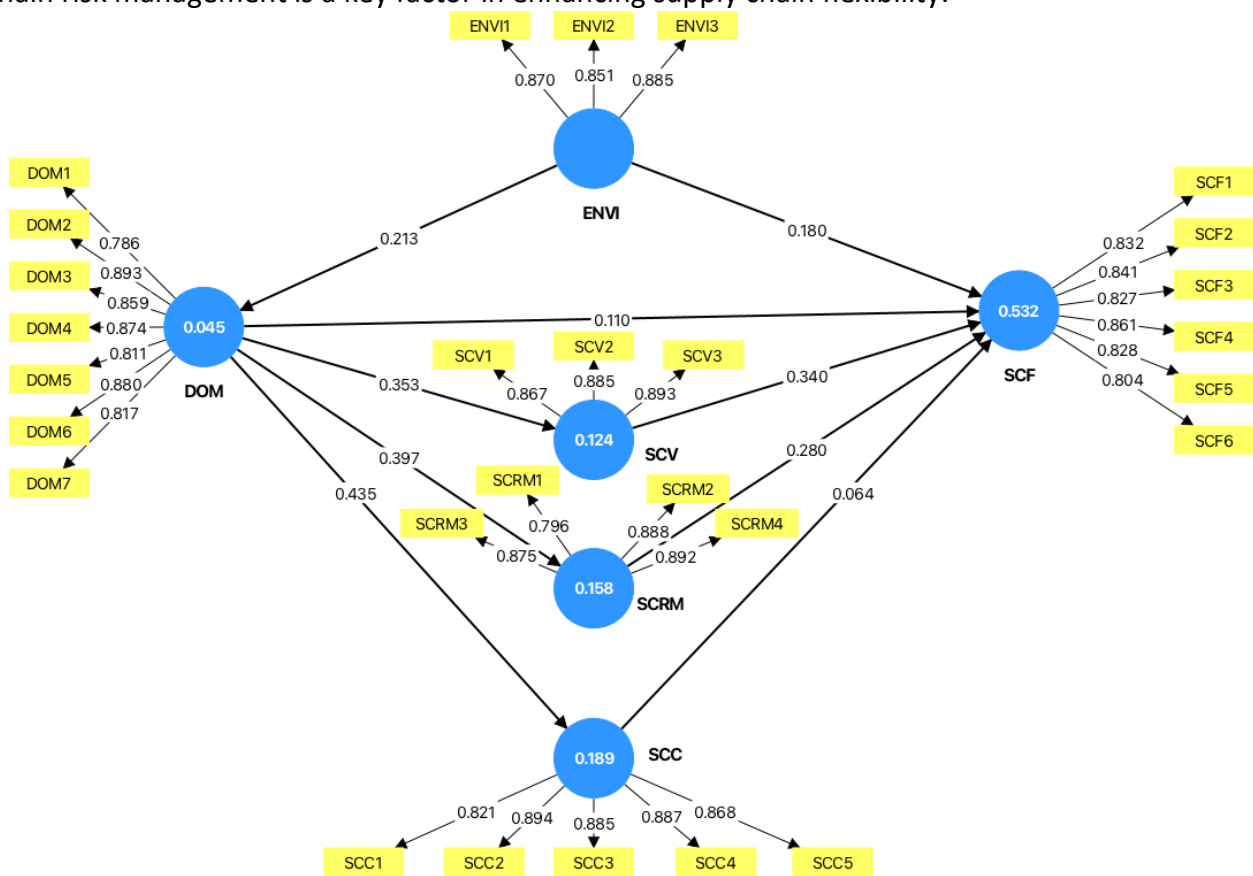


Fig. 2. Results of structural model

The effect size analysis (f^2) provides further insights into the relative contribution of each construct to the model. According to Hair *et al.*, [62], the values 0.02, 0.15, and 0.35 correspond to small, medium, and large effects, respectively. Table 4 shows a clear differentiation in the magnitude of effects across variables. The relationships with medium and fairly strong impacts are mainly associated with the roles of the digitalization (DOM) and visibility (SCV) in the supply chain. Specifically, the impact from DOM to SCC is the strongest with $f^2 = 0.233$, followed by the DOM \rightarrow SCRM ($f^2 = 0.188$), SCV \rightarrow SCF ($f^2 = 0.15$), and DOM \rightarrow SCV ($f^2 = 0.142$) relationships. This confirms that the DOM is the primary driver. Conversely, the remaining relationships, such as ENVI \rightarrow DOM ($f^2 = 0.047$), ENVI \rightarrow SCF ($f^2 = 0.056$), SCRM \rightarrow SCF ($f^2 = 0.095$), and DOM \rightarrow SCF ($f^2 = 0.02$), exhibit small effect sizes. In particular, the relationship between SCC and SCF has an extremely low f^2 value (0.005), which is consistent with the rejection of hypothesis H4b, indicating that this variable has virtually no significant impact on SCF in this research context. Overall, the combination of small and moderate effect sizes suggests that although several relationships are relatively weak, digitalization (DOM) and the business environment (ENVI) remain key drivers of supply chain flexibility.

Table 4
 Results of structural model analysis

Hypothesis	Relationships	Beta	t value	p value	R ²	f ²	Decision
H1	ENVI -> DOM	0.213	4.132	0.000	0.045	0.047	Supported
H2	ENVI -> SCF	0.180	3.687	0.000		0.056	Supported
H3a	DOM -> SCV	0.353	6.884	0.000	0.124	0.142	Supported
H3b	DOM -> SCC	0.435	10.586	0.000	0.189	0.233	Supported
H3c	DOM -> SCRM	0.397	8.716	0.000	0.158	0.188	Supported
H3d	DOM -> SCF	0.110	2.084	0.037		0.02	Supported
H4a	SCV -> SCF	0.340	5.867	0.000		0.15	Supported
H4b	SCC -> SCF	0.064	1.003	0.316		0.005	Not supported
H4c	SCRM -> SCF	0.280	4.226	0.000	0.532	0.095	Supported

4.3 Testing Mediation Effect

Table 5 reports the results of the mediation analysis based on the Variance Accounted For (VAF) criterion. According to Cheung *et al.*, [65], a VAF below 20% indicates no mediation, a value between 20% and 80% reflects partial mediation, and a value above 80% indicates full mediation. In this study, the mediation effects are categorized into two groups. Specifically, the DOM \rightarrow SCC \rightarrow SCF relationship shows a VAF coefficient of 7.59%, below the 20% threshold. This indicates that supply chain collaboration (SCC) does not mediate the relationship between DOM and SCF. In contrast, the VAF values for SCV and SCRM are 32.52% and 30.08%, respectively. These values fall within the 20% to 80% range, confirming partial mediation effects for these two variables. These findings suggest that while DOM has a significant direct impact on SCF, its influence is further strengthened by improved supply chain visibility and effective supply chain risk management.

Table 5
 Variance Accounted For (VAF) Values for parallel mediation analysis

Relationships	Indirect Effect	Total Effect	VAF(%)	Mediation Type
H5 : ENVI->DOM->SCF	0.023	0.259	9.03	No mediation
H6a: DOM -> SCV -> SCF	0.12	0.369	32.52	Partial mediation
H6b: DOM -> SCC -> SCF	0.028	0.369	7.59	No mediation
H6c: DOM -> SCRM -> SCF	0.111	0.369	30.08	Partial mediation

Table 6 presents the results of the sequential mediation analysis assessing whether DOM and supply chain dynamic capabilities jointly transmit the effect of environmental turbulence on SCF. The indirect paths through SCV ($\beta = 0.026$, $t = 2.673$, $p = 0.008$) and SCRM ($\beta = 0.024$, $t = 2.594$, $p = 0.010$) are both positive and statistically significant, supporting the proposed sequential mechanisms. In contrast, the pathway via SCC is not significant ($\beta = 0.006$, $t = 0.923$, $p = 0.356$). These findings indicate that visibility and risk management, but not collaboration, sequentially mediate the relationship between business environmental turbulence and supply chain flexibility.

Table 6
 Sequential mediation of supply chain dynamic capabilities

Relationships (H7)	Indirect Effect	t value	p value	Decision
ENVI->DOM->SCV-> SCF	0.026	2.673	0.008	Supported
ENVI->DOM->SCC-> SCF	0.006	0.923	0.356	Not supported
ENVI->DOM->SCRM-> SCF	0.024	2.594	0.010	Supported

5. Discussion

The results of this study shed light on the complex relationship between the volatility of the business environment, the adoption of digital operations management (DOM), and supply chain flexibility (SCF) among enterprises in Vietnam. The findings not only confirm the pivotal role of DOM in enhancing SCF but also highlight the underlying mechanisms operating through supply chain dynamic capabilities.

Firstly, the research results confirm that the volatile business environment (ENVI) is a driving force behind enterprises' adoption of digital operations management (DOM). This finding is consistent with Dubey *et al.*, [57], who argued that environmental pressure and market context are important drivers of enterprises' adoption of digital technologies. In Vietnam, where the business environment is increasingly unstable, investment in DOM has shifted from a supporting option to a core strategic task, shaping business resilience and sustainable development.

Secondly, the study demonstrates that DOM has a direct and positive impact on all three core supply chain competencies: collaboration (SCC), visibility (SCV), and risk management (SCRM). Specifically, digitalization of operational processes enhances information sharing, facilitates joint decision-making, and enables real-time monitoring, thereby strengthening collaboration and improving visibility across the supply chain.

Thirdly, SCV and SCRM have both parallel and sequential mediation effects on the relationships of DOM-SCF and ENVI-SCF. This result aligns with prior studies suggesting that supply chain capabilities act as complementary mediators that enhance the positive influence of digital technologies on supply chain outcomes [14, 57].

Interestingly, SCC does not exhibit a significant mediating effect and has no direct influence on SCF, in contrast to previous research [31]. This can be explained by the predominance of small and medium-sized enterprises (SMEs) and the loose linkages among domestic firms. These businesses often prioritize short-term operational goals over long-term strategic collaboration and have limited participation in global supply chains. However, as part of the roadmap for deeper integration into global supply chain management, promoting SCC remains a crucial requirement for firms to enhance their resilience to market fluctuations.

6. Conclusion and Future Research

Our study provides robust evidence that the digitalization of operations management (DOM) plays a pivotal role in enhancing supply chain flexibility (SCF). Rather than merely posing challenges, environmental turbulence can act as a driver for the digitalization of operations management across

firms, ultimately strengthening supply chain flexibility. Importantly, digitalization should not be viewed as a capability in itself, but rather as a critical enabler for the development and deployment of supply chain dynamic capabilities. Beyond its direct effect, DOM indirectly strengthens SCF by reinforcing key intermediary capabilities, namely supply chain collaboration (SCC), supply chain visibility (SCV), and, in particular, supply chain risk management (SCRM), which exhibits the strongest mediating effect. These results provide deeper insights into the mechanisms by which digitalization enhances supply chain flexibility, extending prior research that has primarily focused on the adoption of Industry 4.0 technologies without explicitly explaining the underlying capability-building processes. From a theoretical perspective, this study contributes to the dynamic capabilities literature by demonstrating how DOM enables firms to develop critical intermediate capabilities that facilitate adaptive responses to environmental turbulence. By unpacking the parallel and sequential mediating roles of SCC, SCV, and SCRM, the study advances understanding of how operational digitalization translates into greater flexibility under volatile and uncertain conditions. From a managerial perspective, the findings suggest that firms seeking to enhance supply chain flexibility should align their digitalization initiatives with strategies to strengthen collaboration, transparency, and risk management through digital tools, rather than treating digital technologies as standalone solutions.

Nevertheless, this study is subject to limitations. First, the cross-sectional design restricts the ability to capture the evolutionary nature of digital capability development. Second, the empirical evidence is drawn exclusively from Vietnamese firms. Future research is encouraged to adopt longitudinal designs and extend the analysis to other industries and cross-national contexts to further validate and generalize the proposed framework. Third, the non-significant role of collaboration suggests the need for further in-depth investigation of this important variable across different business contexts.

Author Contributions

Conceptualization, T.H.T.; methodology, T.H.T.; software, T.H.T.; validation, T.H.T.; T.C.T.V. and T.H.D.L.; formal analysis, T.C.T.V.; investigation, T.C.T.V.; resources, T.H.T.; T.C.T.V. and T.H.D.L.; data curation, T.H.T.; T.C.T.V. and T.H.D.L.; writing—original draft preparation, T.H.T.; T.C.T.V. and T.H.D.L.; writing—review and editing, T.H.T.; visualization, T.H.T.; T.C.T.V. and T.H.D.L.; supervision, T.H.T.; project administration, T.H.T.; funding acquisition, T.H.T. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

All the analyzed data are included in the manuscript. The raw data will be available on reasonable request to the corresponding author.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The funders had no role in

the design of the study; in the collection, analyses, or interpretation of data; or in the decision to publish the results.

Declaration of Generative AI and AI-Assisted Technologies in the Manuscript Preparation Process

During the preparation of this work, the authors used AI-assisted tools Grammarly and ChatGPT to check formatting, spelling, and grammar of the text. These tools were not used to generate scientific content, analyses, or conclusions. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the final manuscript. No generative AI tools were used to create or modify the study figures or artwork.

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