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A Neutrosophic Causality Analysis (NCA) for Critical Success Factors of Humanitarian Logistics Management during Disaster

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Abstract: Humanitarian logistics management (HLM) is critical for effective disaster response and risk mitigation in disaster-prone regions like Vietnam, where unpredictable natural disasters complicate the identification of critical success factors (CSFs). This study employs a quantitative approach, utilizing insights from 50 experienced humanitarian logistics experts in Vietnam to create an unbiased dataset. By integrating Multi-Criteria Decision Making (MCDM) with Neutrosophic Sets (NSs), the research applies NS-Delphi for expert consensus, Neutrosophic Decision Making Trial and Evaluation Laboratory (NS-DEMATEL) to evaluate CSF interrelationships, and Neutrosophic Weighted Aggregated Sum Product Assessment (NS-WASPAS) to prioritize strategies. The analysis encompasses 50 variables across five dimensions: Strategic, Operational, Technological, Financial and Resource Management, and Social and Environmental factors. Findings emphasize the critical role of Technological, Financial, and Resource Management as system levers, urging humanitarian organizations to prioritize technological and financial capacities while enhancing EF integration to build a more responsive, flexible, and sustainable HLM system amidst global challenges. Key strategies prioritized include digital transformation, strategic planning, policy development, data-driven disaster response, and enhanced last-mile delivery capabilities, all vital for improving HLM effectiveness. These insights provide policymakers with a robust framework to strengthen HLM, ensuring timely and equitable relief operations in Vietnam's complex disaster landscape.

Keywords: Humanitarian Logistics; NS-Delphi; NS-DEMATEL; NS-WASPAS; Vietnam; MCDM; Disaster management

1. Introduction

1.1. Research Background

For the last several years, there has been a surge in the number and intensity of natural disasters, primarily because of climate change, environmental degradation, and urbanization. Natural calamities such as hurricanes, earthquakes, floods, wildfires, and pandemics are not only the causes of massive human and property losses but also the reasons for the humanitarian crises that affect many people in the world; the solution is the prompt and efficient reaction of governments, humanitarian organizations, and the international community [1]. A typical example is the earthquake in Turkey on the 6th of February 2023; more than 50,000 people were killed after the first two earthquakes, and several buildings and structures were destroyed, while Turkey lost more than 163 billion EUR [2]. Another example that can be mentioned is Cyclone Helene, which landed on September 24, 2024, facing powerful winds and floods on its track, because of which more than 230 people died, and the costs of $200 billion went down. According to Vietnamnews [3], typhoon Yagi struck Vietnam, emerging as one of the most destructive storms in history. It caused widespread devastation across multiple provinces, resulting in significant loss of life and property. Reports indicate that by September 13, 2024, typhoon Yagi and the ensuing floods led to 336 people dead or missing, with Lao Cai, Cao Bang, and Yen Bai provinces suffering the greatest impact. The agricultural sector was severely hit, with approximately 195,929 hectares of rice fields submerged and 35,010 hectares of other crops damaged, causing substantial economic losses for the region [3].

The devastating impact of natural disasters not only results in loss of lives and property but also disrupts livelihoods, highlighting the crucial need for inter-agency cooperation and efficient humanitarian logistics management to ensure the timely and proper allocation of resources, minimize damage, and protect human lives. Humanitarian logistics is the lifeline for efficient disaster relief operations, essential in sending aid to the affected communities[4]. Humanitarian logistics enables organizations to efficiently plan, coordinate, and execute procurement, transportation, storage, and last-mile delivery, ensuring timely aid for disaster victims while also bridging critical functions like preparedness and response, procurement and distribution, and central and field operations to manage large-scale relief efforts effectively [5]. Moreover, the extent to which logistics decides the rate of humanitarian activities and the speed of their operations is responsible for ensuring the timely delivery of essential goods and services, such as food, medicine, shelter, and clean water, to people affected by the crisis. Regarding disaster response, logistics stands out as one of the most demanding resource-intensive fields of the whole relief effort, which requires large monetary investment, technical know-how, and multi-level coordination [4]. However, operations are often hampered by damaged infrastructure, limited transportation and storage capacity, poor last-mile delivery in remote areas, and weak coordination among agencies. Many responses remain reactive rather than proactive, with inadequate investment in preparedness and real-time data systems. These limitations often lead to delays, misallocation of resources, and unmet needs during emergencies, especially in low- and middle-income countries.

1.2. Research Motivation

Vietnam ranks among the most disaster-prone nations in the Asia-Pacific, placing 91st out of 191 countries on the 2019 INFORM Risk Index. Its 3,260 km coastline along the East Sea and diverse terrain make it highly susceptible to natural disasters, particularly floods. Tied with Bangladesh for the highest flood risk globally, Vietnam frequently experiences river floods, flash floods, and coastal flooding [6]. Floods are the most recurrent and destructive disasters, impacting millions annually. Over the past two decades, Vietnam has faced 330 disaster events, resulting in nearly 9,000 deaths and economic losses exceeding $4.4 billion, according to the 2020 CRED report. More than 70% of the population is affected by these disasters, disrupting lives, damaging infrastructure, and hindering economic progress (see **Table 1**). Rural and coastal communities are especially vulnerable, facing displacement, loss of agricultural production, and heightened food insecurity.

Table 1: Total human and property losses due to natural disasters in Vietnam, 2014-2025

Disaster type	Events	Deaths	People Affected	Damages ('000 US$)
Drought	**4**		**3,111,558**	**6,802,120**
Drought	4		3,111,558	6,802,120
Epidemic	**3**	**70**	**79,287**	
Infectious disease	1	16	83	

Viral disease	2	54	79,204	
Flood	**69**	**1,739**	**9,870,637**	**3,753,396**
Coastal flood	2	129	566,130	480,000
Flash flood	14	360	1,087,954	566,500
Riverine flood	28	980	6,593,810	2,506,029
Flood (General)	25	270	1,622,743	200,867
Storm	**76**	**2,398**	**22,696,311**	**11,521,849**
Lightning/Thunderstorms	2	19	30,076	
Extra-tropical storm	1	5	4,652	1,500
Tropical cyclone	62	2,295	22,324,817	11,356,349
Hail	1	13		10,000
Severe weather	5	16	91,849	10,000
Storm (General)	4	48	190,505	144,000
Others	1	2	54,412	
Industrial accident	**13**	**254**	**142**	**2,939**
Fire	1	17	21	
Collapse	3	64	80	2,939
Miscellaneous accident	9	173	41	
Transport accident	**20**	**396**	**245**	**0**
Air	2	32	5	
Rail Rail	1	11	70	
Road	7	125	95	
Water	10	228	75	
Grand Total	**330**	**8,922**	**71,515,870**	**44,157,669**

Source: [7]

Despite Vietnam's comprehensive disaster prevention and recovery policies, its humanitarian aid system faces significant implementation challenges. Fragmented coordination between government agencies and NGOs, inadequate logistics infrastructure in rural and mountainous areas, and the absence of real-time data integration for emergency preparedness undermine response effectiveness. These issues were evident during major disasters like Typhoon Molave and the Central Vietnam floods in 2020, as well as Typhoon Yagi in 2024, where delays in aid delivery, insufficient supplies, and transportation bottlenecks hindered assistance to affected communities.

Compared to countries with similar disaster profiles, such as the Philippines and Bangladesh, Vietnam's challenges are exacerbated by its geography and centralized disaster management structure. The Philippines employs a decentralized system, empowering barangays (villages) to manage local disaster plans for faster response. Bangladesh has prioritized early warning systems, enhancing community preparedness and reducing loss of life.

Vietnam's disaster response remains highly centralized, often causing delays in resource mobilization and limiting adaptability to local conditions. Unlike the Philippines [8] and Bangladesh [8], which leverage geographic information systems (GIS) and mobile-based technologies for humanitarian efforts, Vietnam has yet to harness these tools fully. Another key challenge is the lack of coordination between government agencies and NGOs. Despite Vietnam's robust state machinery and well-defined disaster response strategies, official emergency plans often overshadow or vaguely outline the roles of local and international NGOs. This leads to neglected areas and duplicated efforts. For instance, during Typhoon Yagi in 2024, some NGOs faced difficulties accessing affected zones due to poor real-time information sharing and unclear authorization protocols.

The lack of integrated logistical systems in Vietnam has led to uneven aid distribution, with multiple shipments overwhelming some sites while others are neglected. This underscores the need for a more responsive and efficient humanitarian logistics system tailored to Vietnam's unique challenges. Regional examples, such as empowering local actors, establishing decentralized logistics hubs, and implementing real-time coordination platforms, demonstrate ways to enhance the timeliness and equity of disaster response.

To address these issues effectively within Vietnam's geographical, social, and institutional context, identifying the Critical Success Factors (CSFs) for humanitarian logistics management is essential. This study employs the Neutrosophic Causality Analysis (NCA) tool to investigate and analyze causal relationships among CSFs systematically. By handling uncertain and imprecise data, common in emergencies, NCA offers actionable insights to optimize policy formulation and practical implementation, ultimately improving the effectiveness of humanitarian logistics in Vietnam.

Effective humanitarian aid management during emergencies requires swift and precise handling of complex, uncertain information. Decision-making in humanitarian logistics must be flexible and robust to cope with unpredictable conditions like incomplete data, damaged infrastructure, and adverse weather. Multi-Criteria Decision-Making (MCDM) methods—such as Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR), and Multi-Objective Optimization based on Ratio Analysis (MOORA)—are commonly used to prioritize and assess critical factors in supply chain management. However, these traditional MCDM methods have limitations in humanitarian contexts. They typically require precise numerical inputs, which are impractical for capturing the ambiguity of human judgment under time pressure and data scarcity [9]. Moreover, they assume well-defined criteria and reliable data, conditions rarely met in disasters marked by unpredictability and information gaps. Conventional MCDM methods also struggle to account for uncertainties from fluctuating resource availability, infrastructure disruptions, and environmental variability [10].

To address these shortcomings, this study explores advanced uncertainty modeling frameworks, focusing on neutrosophic sets (NS) for their ability to handle indeterminate and inconsistent information prevalent in humanitarian logistics. A comparative analysis of fuzzy set extensions is presented to highlight their applicability (as shown in **Table 2)**. Fuzzy Sets (FS), introduced by Zadeh (1965) [11], exhibit uncertainty by assigning membership degrees ($ƒ \in [0,1]$) to elements, effectively capturing vagueness but failing to address indeterminacy or conflicting information. Interval-valued fuzzy Sets (IVFS), proposed by Zadeh (1975) [12], extend FS by using interval-based membership degrees to represent ambiguity better, yet they lack mechanisms for non-membership or hesitancy. Intuitionistic Fuzzy Sets (IFS), developed by Atanassov (1999) [13], incorporate both membership ($ƒ$) and non-membership (ŧ) degrees, constrained by $0 \leq ɟ + ŧ \leq 1$, offering improved flexibility for incomplete information but limiting expressiveness when the constraint is violated. Pythagorean Fuzzy Sets (PyFS), introduced by Yager (2013) [14], relax this constraint to $0 \leq ɟ^2 + ŧ^2 \leq 1$, enhancing decision-making flexibility, though they cannot handle cases exceeding this boundary. Yager's q-Rung Orthopair Fuzzy Sets (q-ROFSs) (2016) [15] further generalize this by allowing $0 \leq ɟ^u + ŧ^u \leq 1$ $(u \geq 1)$, adapting to diverse uncertainty scenarios but complicating expert assessments. Picture Fuzzy Sets (PFSs), proposed by Cuong (2014) [16], include neutral membership degrees (p) with $0 \leq ɟ + ŧ + p \leq 1$, improving the representation of neutral or hesitant information but remaining restrictive due to the summation constraint. Spherical Fuzzy Sets (SFSs), developed by Kutlu Gündoğdu and Kahraman (2018) [17], extend PFSs with $0 \leq ɟ^2 + ŧ^2 + p^2 \leq 1$, offering greater decision-making freedom at the cost of computational complexity. Z-numbers, introduced by Zadeh (2011) [18] as Z(A, B), combine fuzzy restrictions with reliability measures but cannot independently model membership degrees, limiting their scope in conflicting scenarios. Neutrosophic Sets (NS), proposed by Smarandache (1998) [19], provide a robust framework for humanitarian logistics by independently modeling truth (ɟ), indeterminacy (p), and falsity (ŧ) membership functions, each within [0,1], with a relaxed constraint of $0 \leq ɟ + ŧ + p \leq 3$. This flexibility enables NS to effectively capture incomplete, inconsistent, and indeterminate information inherent in disaster scenarios. Single-Valued Neutrosophic Sets (SVNSs) further simplify NS for practical applications by ensuring single-valued components, enhancing computational tractability.

Compared to FS, IVFS, IFS, PyFS, PFSs, q-ROFSs, SFSs, and Z-numbers, NS and SVNS offer superior handling of uncertainty by allowing independent representation of conflicting and indeterminate states, making them highly suitable for dynamic decision-making in humanitarian logistics. NS's ability to model truth, falsity, and indeterminacy independently addresses the limitations of traditional MCDM and other fuzzy extensions, providing a powerful tool for synthesizing unreliable data and supporting equitable, rapid relief efforts in unpredictable environments [20], [21], [22].

Table 2: Comparisons of Various Fuzzy Sets

Author	Fuzzy Sets	ʄ	ŧ	ꝑ	Uncertainty	Constraints	Advantages	Disadvantages
Zadeh (1965) [11]	FS	Yes	No	No	Yes	0≤ ʄ ≤1	Widely applied in various domains handling uncertainty, such as control systems and decision-making.	Limited in modeling complex uncertainties, particularly those involving incomplete or indeterminate information.
Zadeh (1975) [12]	IVFS	Yes	Yes	No	Yes		Captures uncertainty with interval-based membership, offering more flexibility than single-valued FS.	It does not account for non-membership or hesitancy, limiting its ability to model conflicting information.
Atanassov (1999) [13]	IFS	Yes	Yes	No	Yes	0≤ ʄ+ŧ ≤1	Effectively handles insufficient information by incorporating both membership and non-membership degrees.	The sum of membership and non-membership may restrict expressiveness when exceeding the unit interval.
Yager (2013) [14]	PyFS	Yes	Yes	No	Yes	$0 \leq ʄ^{2} + ŧ^{2} \leq 1$	Offers flexibility for decision-makers in scenarios with hesitation, improving the representation of uncertainty.	Fails to model cases where the sum of squared membership and non-membership exceeds 1.
Cuong (2014) [23]	PFSs	Yes	Yes	Yes	Yes	0≤ ʄ+ꝑ+ŧ ≤1	Robustly handles complex, unreliable information by including hesitancy, suitable for intricate decision-making.	Constraints on the sum of three grades (≤ 1) may limit applicability in some indeterminate scenarios.
Yager (2016) [15]	q-ROFSs	Yes	Yes	No	Yes	$0\leq ʄ^{u}+ŧ^{u}\leq 1$	Highly adaptable with adjustable parameters, accommodating diverse uncertainty modeling needs.	Collecting and assessing expert information can be challenging due to parameter flexibility.
Kutlu Gündoğdu & Kahraman (2018) [17]	SFSs	Yes	Yes	Yes	Yes	$0\leq ʄ^{2}+ꝑ^{2}+ŧ^{2} \leq 1$	Provides greater decision-making freedom with spherical geometry-based constraints, enhancing flexibility.	Complex computations may pose challenges in practical implementation and scalability.
Zadeh (2011) [18]	Z-number	Yes	No	No	Yes	$\leq Z(A,F) \leq 1$	Models of real-world systems with reliability constraints enhance decision-making under partial information.	Lacks independent representation of non-membership or indeterminacy, limiting its scope.
Smaradache (1998) [19]	*Neutrosophic Sets (NS)*	Yes	Yes	Yes	Yes	0≤ ʄ+ꝑ+ŧ ≤3	Powerfully addresses incomplete, indeterminate, inconsistent information, ideal for real-world complexities.	Requires sophisticated computational methods to handle three independent degrees, increasing complexity.

Notes: ʄ = (Membership); ŧ = (Non-membership); ꝑ = (Hesitancy/Indeterminacy)

1.3. Research Questions and Objectives

This study aims to identify and prioritize CSFs for humanitarian logistics management in the context of disaster response in Vietnam, addressing the complexities of uncertainty and indeterminacy inherent in such scenarios. The research objectives are as follows:

(i) To identify key factors influencing humanitarian logistics management during post-disaster phases in Vietnam.

(ii) To analyze the cause-and-effect relationships among CSFs, quantify their impact on humanitarian logistics management, and determine their root causes.

(iii) To prioritize strategic interventions for effective humanitarian logistics management by integrating NS-MCDM models to account for uncertainty and vagueness.

A panel of 50 experienced humanitarian logistics experts in Vietnam was assembled to ensure robust and reliable findings. These experts provide comprehensive, multi-dimensional insights into CSFs and strategies to enhance logistics efficiency. The following research questions guide the study:

(i) What are the primary factors affecting humanitarian logistics management during disasters in Vietnam?

(ii) What are the causal relationships among CSFs, their impacts on humanitarian logistics management, and the underlying root causes?

(iii) How can strategic decision-making models incorporate uncertainty and vagueness to optimize humanitarian logistics strategies?

1.4. *Research Contributions*

This study makes significant contributions to the field of HLM, particularly in the context of Vietnam's unique geographical, social, and institutional environment. By addressing the challenges of disaster response in Vietnam through a scientific and data-driven approach, this research provides actionable insights and practical solutions tailored to the country's needs.

- Development of a context-specific framework for Vietnam: This study addresses these challenges by developing a scientific framework tailored to Vietnam's socio-institutional and environmental context. Unlike generic models that may not account for local nuances, this research integrates Vietnam-specific factors to propose feasible and effective solutions. For instance, the study considers the centralized decision-making structure of Vietnam's disaster management system and proposes strategies to enhance coordination between government agencies, NGOs, and local communities.
- Application of Neutrosophic Causality Analysis (NCA): A core contribution of this study lies in the novel application of the NCA tool to investigate causal relationships among CSFs in humanitarian logistics. NCA is particularly suited to handling uncertain, imprecise, and indeterminate data—a common occurrence in emergency scenarios where information is often incomplete or rapidly changing. By employing NCA, this study provides a comprehensive and scientifically rigorous analysis of how various CSFs (e.g., resource availability, coordination mechanisms, and technological infrastructure) interact and influence the effectiveness of humanitarian logistics.
- Integration of Neutrosophic sets-based methods: This study pioneers integrating three NS-based methods (NS-Delphi, NS-DEMATEL, and NS-WASPAS) to enhance decision-making in humanitarian logistics.
- Advancement of sustainable and equitable humanitarian logistics: This study contributes to establishing a sustainable, rapid, and equitable humanitarian logistics system for relief distribution in Vietnam. The NS-based approach excels at handling uncertain data,

enabling the design of logistics systems responsive to dynamic disaster scenarios. The proposed solutions prioritize fairness in resource allocation, ensuring that vulnerable populations in remote or underserved areas receive timely aid. Additionally, the study emphasizes sustainability by advocating for resource optimization and using advanced technologies, such as digital platforms for real-time tracking and coordination, to reduce waste and improve long-term disaster preparedness.

- Alignment with Global Humanitarian Logistics Goals: This study aligns with global calls for innovative, technology-driven, and localized solutions in humanitarian logistics. By proposing solutions such as digitalization, real-time data analytics, and data-driven decision-making, the research contributes to the broader discourse on improving HLM in developing countries. The emphasis on local adaptation ensures that the proposed solutions are innovative and practical for resource-constrained settings. This contribution bridges the gap between theoretical advancements in decision-making methodologies and their practical application in real-world humanitarian challenges.

The study is structured as follows: Section 2 reviews the literature on humanitarian logistics, emphasizing CSFs and decision-making challenges. Section 3 outlines the theoretical foundations of NS and their operators in MCDM frameworks. Section 4 presents the analysis of collected data, contextualized within Vietnam's disaster response environment, and discusses key findings. Section 5 concludes with theoretical and practical implications, study limitations, and directions for future research.

2. Literature Review

2.1 Literature Review on Humanitarian Logistics

Humanitarian logistics has evolved from a reactive operational function to a strategic, data-driven discipline driven by the' increasing frequency and complexity. Recent studies emphasize the need for innovation and agility in humanitarian logistics to address unpredictable disruptions, such as pandemics and natural calamities. Altay et al.[24] highlight that advanced technologies and adaptive methodologies significantly enhance logistics responsiveness and efficiency. Key components of humanitarian logistics—needs assessment, procurement, transportation, warehousing, and distribution—have been focal points for integrating emerging technologies. For instance, Van Steenbergen et al.[25] Propose a hybrid model combining trucks and unmanned aerial vehicles (UAVs) to optimize post-disaster inventory distribution, demonstrating potential improvements in service delivery. Procurement strategies are also advancing, with adaptations of Kraljic's procurement framework incorporating risk, supplier relationships, and responsiveness to suit humanitarian contexts (The Financial Analyst, 2024) [26]. However, natural disasters like the 2024 Port Vila earthquake and Yemen floods often devastate infrastructure, rendering logistics networks vulnerable and underscoring the need for resilient, integrated disaster planning. Flexible, localized supply chains are essential to ensure timely and effective support in dynamic, resource-constrained environments.

Despite these advancements, significant gaps persist in HLM, particularly in the Global South, such as Vietnam. The literature predominantly focuses on post-disaster response, with limited attention to pre-disaster preparedness and long-term recovery strategies. Nguyen et al. [27] highlight the complexities of flood risks in urban Central Vietnam, advocating for comprehensive, proactive risk management to address all disaster phases. This imbalance hinders the development of holistic HLM frameworks that support the entire disaster lifecycle. Emerging technologies, including UAVs, blockchain, and artificial intelligence, show promise but face scalability challenges in low-resource settings due to infrastructure limitations and insufficient evidence of large-scale efficacy [25]. Fragmented coordination among stakeholders—governments, NGOs, private sectors, and military entities—continues to cause inefficiencies, duplication, and delays in aid delivery [28]. Furthermore, excluding community perspectives in logistical planning often results in culturally inappropriate interventions, reducing their effectiveness [29]. In disaster-prone countries like Vietnam, the lack of integrated, localized, and community-centered HLM approaches remains a critical barrier to building resilient and adaptive logistics systems.

2.2 Research Gaps

The escalating frequency and severity of natural disasters underscore the critical role of HLM in ensuring effective disaster response. Despite advancements, HLM faces persistent challenges, including uncertainty, incomplete data, and volatile environments, necessitating innovative decision-making frameworks. MCDM, FS, and extended fuzzy sets are widely adopted in HLM research to enhance decision-making, resource allocation, and supply chain optimization. However, these methods have limitations. MCDM relies on precise data, rendering it less effective in highly uncertain disaster scenarios with incomplete or ambiguous information. FS and EFS improve uncertainty modeling but suffer from subjective membership function definitions, which can complicate result interpretation and reduce consistency. NSs offer a promising solution by incorporating truth, indeterminacy, and falsity degrees, enabling nuanced handling of uncertainty and indeterminacy inherent in HLM. While NSs have been explored in some optimization studies, their integration with MCDM methods in HLM remains underexplored, representing a significant research gap.

Table 3 summarizes related works, highlighting methodologies and domains in HLM research.

Table 3: Related works

No	Author	Methodology	Domain
1	Celik et al.[30]	Type-2 Fuzzy Sets (T2FSs), AHP	Identifying success factors for humanitarian logistics management globally.
2	Saksrisathaporn et al.[31]	AHP, TOPSIS	Optimizing transportation, warehousing, and supplier selection in France.
3	Boltürk et al.[32]	Hesitant Fuzzy Sets (HFSs), AHP	Selecting warehouse locations in Northwest Turkey.
4	Sarma et al.[33]	Neutrosophic Programming, Goal Programming, Pareto Optimal Solution	Minimizing operational costs and distribution time in global humanitarian logistics.
5	Budak et al.[34]	Interval-Valued Intuitionistic Fuzzy (IVIF), DEMATEL, ANP, TOPSIS	Selecting optimal real-time location system technology for logistics warehouses globally.
6	Yılmaz et al.[35]	Interval Type-2 Fuzzy Sets (IT2FSs), AHP, TOPSIS	Locating disaster response centers in Turkey.
7	Mohammadi et al. [36]	Neutrosophic Sets (NSs), Fuzzy Sets (FSs)	Identifying reliable facilities, ensuring equitable relief distribution, and optimizing routing in Iran.
8	Anjomshoae et al. [37]	Hierarchical Multi-Stage Fuzzy Inference System	Measuring performance in humanitarian relief operations in Malaysia and Indonesia.
9	Tari et al.[38]	Grey-Delphi, Grey-DEMATEL	Identifying barriers to humanitarian logistics implementation in India.
10	Ahmad et al.[39]	Fuzzy Delphi, Fuzzy DEMATEL	Analyzing drivers for sustainable humanitarian logistics globally.
11	Yesilcayir et al.[40]	Intuitionistic Fuzzy AHP, Intuitionistic Fuzzy TOPSIS	Selecting efficient transit warehouse locations in Hatay, Türkiye.

For example, Saksrisathaporn et al. [31] employed AHP and TOPSIS to optimize France's transportation, warehousing, and supplier choices. Similarly, Budak et al. [34] integrated Interval-Valued Intuitionistic Fuzzy (IVIF) sets with DEMATEL, ANP, and TOPSIS to select real-time location systems for global logistics warehouses. Yılmaz et al.[35] combined Interval Type-2 Fuzzy Sets (IT2FSs) with AHP and TOPSIS to rank disaster response centers in Turkey, while Tari et al. [38] applied Grey-Delphi and Grey-DEMATEL to identify barriers in India, enhancing resource allocation during disasters. These studies demonstrate

MCDM's utility in structured environments with clear data. However, MCDM methods falter in highly uncertain disaster scenarios characterized by incomplete or volatile information, limiting their effectiveness in dynamic HLM contexts [41]. To address uncertainty, Boltürk et al.[32] used HFSs with AHP to select warehouse locations in Turkey, improving relief efficiency. Anjomshoae et al. [37] developed a Hierarchical Multi-Stage Fuzzy Inference System to assess performance indicators in Malaysia and Indonesia. Ahmad et al.[39] combined Fuzzy Delphi and Fuzzy DEMATEL to create a sustainable HLM evaluation framework globally, while Yesilcayir et al.[40] I applied IFSs with AHP and TOPSIS to optimize the transshipment warehouse selection in Türkiye. Despite these advancements, FS and EFS face challenges due to subjective membership function definitions, leading to inconsistent interpretations and reduced decision-making reliability [42].

Recognizing these limitations, NSs offer a robust alternative by independently modeling truth, indeterminacy, and falsity, making them well-suited for disaster environments where ambiguity and incomplete data prevail [29]. For instance, Sarma et al.[33] utilized Neutrosophic programming with goal programming and Pareto optimal solutions to minimize costs and delivery times globally. Mohammadi et al. [36] integrated NSs with FSs to optimize Iran's facility selection and relief distribution. However, NS applications in HLM remain limited, particularly in combination with MCDM methods like DEMATEL and WASPAS. Current HLM research also lacks comprehensive analyses of CSFs. Celik et al.[30] applied T2FSs and AHP to evaluate CSFs globally, laying a foundation for further exploration. However, most studies focus on operational frameworks or specific regions—France [31], Iran [36], India [38], and Turkey ([32], [35], [40]), with few addressing Vietnam, a disaster-prone country requiring tailored HLM solutions. Global studies often lack region-specific insights, creating a gap in contextually relevant models for Vietnam. To bridge these gaps, this study proposes an integrated framework combining NSs with Delphi, DEMATEL, and WASPAS to identify CSFs, analyze causal relationships, and prioritize strategies in HLM. This approach enhances uncertainty handling, improves decision-making accuracy, and provides actionable insights for Vietnam's disaster response. The framework contributes theoretically by advancing NS applications in HLM and practically by addressing challenges in disaster-prone regions.

2.3 Literature Review on CSFs

A systematic literature review, validated by expert consultation, identified 50 CSFs for humanitarian logistics management. These factors were sourced from research databases, including Scopus, Web of Science, PubMed, IEEE Xplore, and Google Scholar, to ensure comprehensive coverage of peer-reviewed studies. The CSFs are organized into five dimensions: Strategic Factors (SF), Operational Factors (OF), Technological Factors (TF), Financial and Resource Management Factors (FF), and Social and Environmental Factors (EF). This categorization facilitates a structured analysis of their interactions and impacts, supporting effective evaluation and management in HLM. **Table 4** details these CSFs, with references drawn from the aforementioned databases.

Table 4: Critical Success Factors

Dimensions	Code	Factors	Author
Strategic Factors	SF 1	Government Policy and Regulations	*Dube et al.* [43]
	SF 2	Interagency Coordination	*Mohammed Zain et al.* [44]

	SF 3	Disaster Preparedness Planning	*Rodríguez-Espíndola et al.* [45]
	SF 4	Infrastructure Resilience	*Guowei Zhang et al.* [46]
	SF 5	Supply Chain Agility	*Dubey et al.* [47]
	SF 6	Stakeholder Engagement	*Guo et al.* [48]
	SF 7	Risk Assessment and Contingency Planning	*Emrouznejad et al.* [49]
	SF 8	Legal and Institutional Frameworks	*Dube et al.* [43]
	SF 9	International Support and Collaboration	*Keshvari Fard et al.* [50]
	SF 10	Strategic Stockpiling of Relief Goods	*Dufour et al.* [51]
Operational Factors	OF1	Logistics Infrastructure Availability	*Qureshi et al.* [52]
	OF2	Supply Chain Coordination	*Adsanver et al.* [53]
	OF3	Last-Mile Delivery Efficiency	*Balcik et al.* [54]
	OF4	Fleet Management and Transportation Planning	*Pedraza-Martinez et al.* [55]
	OF5	Inventory Management Systems	*Mora -Ochomogo et al.* [56]
	OF6	Cold Chain Logistics	*Comes et al.* [57]
	OF7	Human Resource Capacity	*NIDM.* [58]
	OF8	Standardized Logistics Procedures	*Paciarotti et al.* [59]
	OF9	Adaptive Supply Chain Strategies	*Schiffling et al.* [60]
	OF10	Real-Time Monitoring and Tracking	*Warnier et al.* [61]
Technological Factors	TF1	Digital Platforms for Logistics Coordination	*Akhtar et al.* [62]
	TF2	Big Data Analytics for Decision-Making	*Francesca Fallucchi et al.* [63]
	TF3	Internet of Things (IoT) in Logistics	*Kumar et al.* [64]
	TF4	Blockchain for Transparency and Accountability	*Khan et al.* [65]
	TF5	Drones for Rapid Assessments and Deliveries	*Jin et al.* [66]
	TF6	AI-Based Demand Forecasting	*Nguyen et al.* [67]
	TF7	Automated Warehousing Systems	*Yang et al.* [68]
	TF8	Cybersecurity for Data Protection	*Blond et al.* [69]
	TF9	Mobile Applications for Communication and Coordination	*Abushaikha et al.* [70]
	TF10	Satellite and GIS for Route Optimization	*Oscar Esteban Rodríguez Espíndola.* [71]
Financial and Resource Management Factors	FF1	Budget Allocation for Disaster Logistics	*Fan et al.* [72]
	FF2	Donor Funding and Resource Mobilization	*Jahre et al.* [73]
	FF3	Cost-Effective Procurement Strategies	*Patience Okpeke Paul et al.* [74]
	FF4	Public-Private Partnerships in Logistics	*Nurmala et al.* [75]
	FF5	Insurance Mechanisms for Logistics Operations	*Gajović et al.* [76]
	FF6	Transparent Financial Management	*Stumpf et al.* [77]
	FF7	Sustainability in Humanitarian Logistics	*Rodríguez-Espíndola et al.* [78]
	FF8	Incentive Mechanisms for Humanitarian Supply Chain Participants	*Nurmala et al. [75]*
	FF9	Economic Impact of Disaster Logistics	*Vaillancourt et al.*
	FF10	Efficient Allocation of Resources	*Yu et al.* [79]
	EF1	Community Engagement in Disaster Logistics	*Bealt et al.* [80]

Social & Environmental Factors	EF2	Equitable Distribution of Aid	*Hernández-Leandro et al.* [81]
	EF3	Sustainable Resource Management	*Baharmand* [82]
	EF4	Public Awareness and Education	*Khan et al.* [83]
	EF5	Environmental Impact of Logistics Operations	*Kaspar et al.* [84]
	EF6	Health and Safety of Logistics Personnel	*Jong et al.* [85]
	EF7	Resilience of Local Communities	*Sheppard et al.* [86]
	EF8	Gender-Inclusive Disaster Logistics Planning	*Charls Erik Halder* [87]
	EF9	Social Media for Disaster Communication	*Gupta et al.* [88]
	EF10	Psychosocial Support for Affected Populations	*Sangraula et al.* [89]

2.4 Literature Review on Strategies

A systematic review of literature from databases including Scopus, Web of Science, PubMed, IEEE Xplore, and Google Scholar has enabled the identification of 15 strategies to address deficiencies in HLM in Vietnam, a country prone to frequent natural disasters. These strategies, informed by global research and tailored to Vietnam's context, aim to enhance disaster response resilience, efficiency, and equity. **Table 5** lists these strategies, supported by relevant studies.

Table 5: Potential Strategies

No.	Strategies	Sources
S1	Strategic Planning and Policy Development	*Aghsami et al.* [90]
S2	Prepositioning of Relief Supplies	*Shariati et al.* [91]
S3	Strengthening Public-Private Partnerships (PPP)	*Diehlmann et al.* [92]
S4	Digital Transformation in Humanitarian Logistics	*Jayadi* [93]
S5	Enhancing Last-Mile Delivery Capabilities	*Jin et al.* [94]
S6	Leveraging Social Media and Communication Technologies	*Singh* [95]
S7	Capacity Building and Training	*Khan et al.* [83]
S8	Community-Based Logistics Networks	*Jiang et al.* [96]
S9	Green Humanitarian Logistics	*Boostani et al.* [97]
S10	Multi-Modal Transport System Optimization	*Ertem et al.* [98]
S11	Strengthening Governance and Legal Frameworks	*Commission* [99]
S12	Data-Driven Disaster Response Management	*Kondraganti et al.* [28]
S13	Donor Engagement and Sustainable Funding Models	*Corbett et al. 2022* [100]
S14	Resilient Warehousing and Distribution Hubs	*Aghajani et al. 2023* [101]
S15	Inclusive and Equitable Humanitarian Response	*Dönmez et al. 2025* [102]

These strategies address Vietnam's HLM challenges by integrating global best practices with localized solutions, enhancing preparedness, response efficiency, and equitable aid distribution in disaster scenarios.

3. Methodology

This study employs integrated NS-Delphi, NS-DEMATEL, and NS-WASPAS methods to investigate causal relationships among CSFs and evaluate strategies for improving HLM in Vietnam. It excels in handling uncertain data, such as incomplete disaster impact assessments, by modeling truth, indeterminacy, and falsity, making it ideal for dynamic emergency contexts. The methodology ensures a comprehensive analysis by covering CSF identification, causal relationship mapping, and strategy evaluation, while its adaptability to Vietnam's centralized disaster response system and logistical constraints ensures practical relevance. The multi-criteria, multi-expert framework enhances decision-making accuracy and resilience against biases. However, the methodology has limitations, including reliance on potentially subjective expert input, which requires a diverse and experienced panel to mitigate bias. The computational complexity of neutrosophic numbers demands specialized software and expertise, and data availability may be constrained in rapidly evolving disasters. Scalability to larger systems could also require significant resources. To address these, the study employed a diverse expert panel, validated algorithms, and a focused scope, with future research suggested to explore automated data collection for improved efficiency. Below, we comprehensively explain the methodology, its step-by-step implementation, the rationale for its selection, and its limitations.

3.1 Research process

Figure 1 and Figure 2 illustrate the research flowchart and framework of this study. In Figure 1, three-phase flowcharts are presented along with NS-MCDM models. The first phase focused on identifying critical success factors for humanitarian logistics management operations in Vietnam. This was achieved through a comprehensive literature review, categorizing the CSFs into five main groups: Strategic Factors, Operational Factors, Technological Factors, Financial and Resource Management Factors, and Social and Environmental Factors. The relevance of these CSFs was assessed using a combination of the Delphi method and NSs. In this phase, structured questionnaires were distributed to experts to assess the importance and impact of each CSF. Expert judgments were weighted based on their expertise, job position, work experience, and credentials, with these weights converted into NS values. The data was then aggregated and interpreted to produce accurate and consistent results, ensuring reliable expert input throughout the research process. CSFs not meeting the established criteria will be excluded from further analysis.

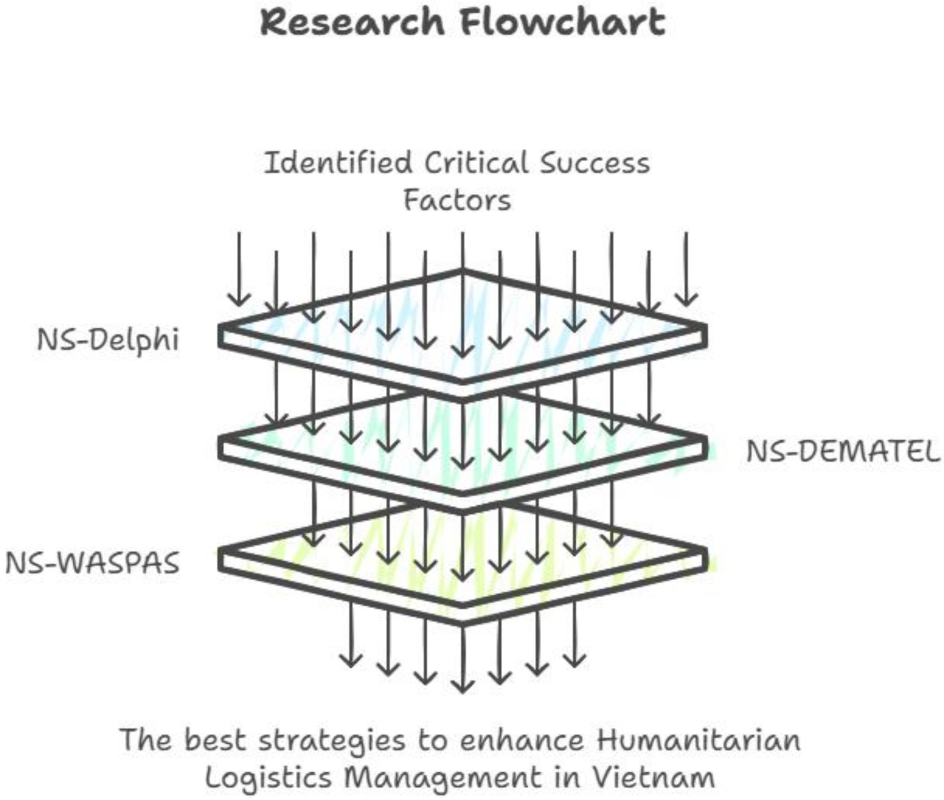

Figure 1: Proposed research flowchart

The second phase investigates the relationships between the validated CSFs using the NS-DEMATEL method. This phase helps clarify the complex dependencies between the elements, thereby mapping the causal relationships to support effective decision-making. The NS-DEMATEL analysis generates an influence matrix that quantifies the impact of each CSF on other elements in the humanitarian logistics system. The analysis results identify causal factors (those that strongly influence the system) and outcome factors (those that are most affected), thereby helping to improve relief distribution strategies, optimize humanitarian supply chains, and enhance crisis response capabilities in Vietnam. In the final stage, the NS-WASPAS method helps rank relief strategies by combining the WSM (Weighted Sum Model) and WPM (Weighted Product Model). Thanks to the ability to synthesize information from many factors, WASPAS helps managers determine the optimal strategy, ensuring the distribution of relief goods quickly, effectively, and in accordance with actual conditions, especially in the context of natural disasters and crises in Vietnam.

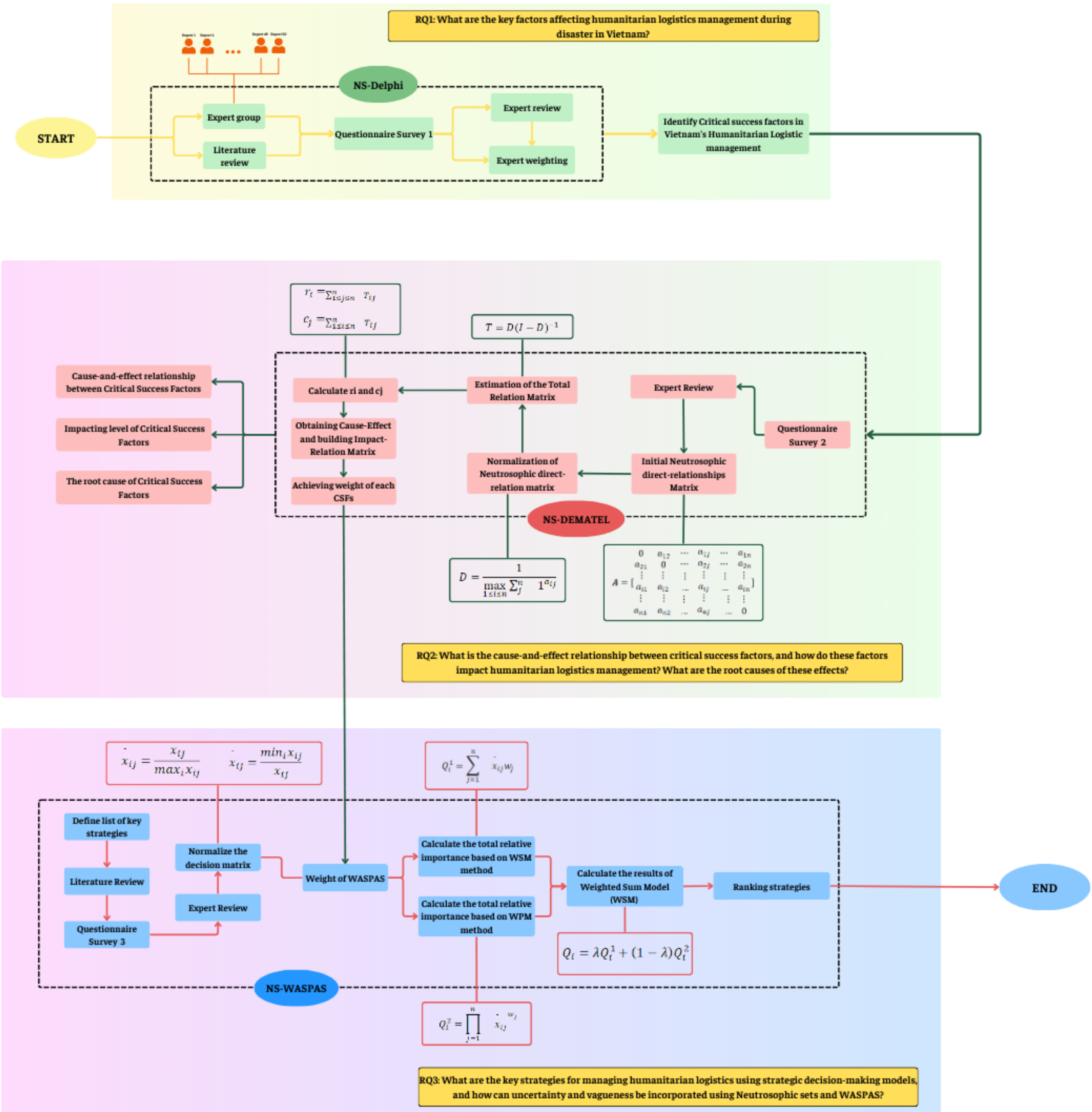

Figure 2: Proposed research frameworks

Data analysis was conducted using VBA-Microsoft Excel 2019, with input from 50 experts to process and evaluate 50 CSFs and rank the different strategies in approximately 150 minutes.

3.2 Preliminaries

NS is a generalization of FS and IFS, characterized by the truth membership function (ꞙ), indeterminacy membership function (ꝑ), and falsity membership function (ŧ). In NSs, indeterminacy is quantified, and the truth, indeterminacy, and falsity membership degrees are assigned independently, with their total sum reaching a maximum of 3.

Definition 1. Let Ⱳ be the universe, where each point is denoted as $x \in ω$. A neutrosophic set A in Ⱳ characterized by the truth membership function $ꞙ_A(x)$, Indeterminacy membership function $ᵽ_A(x)$, Falsity membership function $ŧ_A(x)$. Specially, $ꞙ, ᵽ, ŧ: \mathcal{X} \rightarrow$ $] \ {}^{-}0, 1^{+}[$ represent as the degree of truth membership, the degree of indeterminacy, and the degree of false membership, respectively. Such that ${}^{-}0 \leq sup ꞙ(x) + sup ᵽ(x) + sup ŧ(x) \leq 3^{+}$ means that the sum of the highest values (supremum) must be between 0 and 3.

Definition 2. Let Ⱳ be a space of points (objects), and each object is denoted by x . A single-valued neutrosophic sets (SVNSs) A in Ⱳ is stated as $A = \{ (x, ꞙ(x), ᵽ(x), ŧ(x)) \mid x \in ω \}$. In which:

$ꞙ_A(x)$ refers to the truth-membership function, which indicates how strongly the element x is considered part of the set.

$ᵽ_A(x)$ describes the indeterminacy-membership function, reflecting the uncertainty about whether x belongs to the set.

$ŧ_A(x)$ defines the falsity-membership function, quantifying the extent to which x is regarded as not belonging to the set.

The output of each function lies within the interval [0,1], such as $0 \leq ꞙ_A(x) + ᵽ_A(x) + ŧ_A(x) \leq 3$. For convenience, we call a pair $A = (ꞙ_A; ᵽ_A; ŧ_A)$ as Single-Valued Neutrosophic Number (SVNN)

Definition 3. Consider two SVNNs, denoted as $p = (ꞙ_p; ᵽ_p; ŧ_p)$and $h = (ꞙ_h; ᵽ_h; ŧ_h)$. The mathematical operations that can be carried out on these numbers are presented below:

$$p \supseteq h \iff ꞙ_p \geq ꞙ_h,\ ᵽ_p \leq ᵽ_h,\ ŧ_p \leq ŧ_h \tag{1}$$

$$p = h \Leftrightarrow p \supseteq h \ and\ h \supseteq p \tag{2}$$

$$p \cup h \Leftrightarrow ꞙ_p \vee ꞙ_h ,\ ᵽ_p \wedge ᵽ_h,\ ŧ_p \wedge ŧ_h \tag{3}$$

$$p \cap h \Leftrightarrow ꞙ_p \wedge ꞙ_h ,\ ᵽ_p \vee ᵽ_h,\ ŧ_p \vee ŧ_h \tag{4}$$

$$p^c = (ꞙ_p,\ 1 - ᵽ_p,\ ŧ_p) \tag{5}$$

The complement reverses the roles of truth and falsity while adjusting indeterminacy as $1 - ᵽ_p$

Addition of two SVNNs

$$p \oplus h = (ꞙ_p + ꞙ_h - ꞙ_p ꞙ_h,\ ᵽ_p ᵽ_h,\ ŧ_p ŧ_h) \tag{6}$$

Multiplication of two SVNNs

$$p \otimes h = (ꞙ_p ꞙ_h,\ ᵽ_p + ᵽ_h - ᵽ_p ᵽ_h,\ ŧ_p + ŧ_h - ŧ_p ŧ_h) \tag{7}$$

Scaling an SVNN by a positive constant $l\ (l > 0)$

$$lp = \left(1 - (1 - ꞙ_p)^l,\ ᵽ_p^l,\ ŧ_p^l\right) \tag{8}$$

Raising an SVNN to the power of $l\ (l > 0)$

$$p^l = \left(ꞙ_p^l,\ 1 - (1 - ᵽ_p)^l,\ 1 - (1 - ŧ_h)^l\right) \tag{9}$$

Definition 4. This section presents a weighted aggregation technique for combining multiple Single-Valued Neutrosophic Numbers (SVNNs). Let $\beta_j = \left(ƚ_{\beta_j}, ƥ_{\beta_j}, ƫ_{\beta_j}\right)$ represent the set of SVNNs, where j = 1,2,...,n. Each SVNN is characterized by three distinct membership functions that quantify the degrees of truth, indeterminacy, and falsity.

The Single-Valued Neutrosophic Weighted Aggregation Arithmetic (SVNWAA) operator for the given set of SVNNs is defined and computed using the following formulation:

$$SVNWAA(\beta_1, \beta_2, \dots, \beta_n) = \sum_{j=1}^{n} w_j \beta_j = \left\langle 1 - \prod_{j=1}^{n} \left(1 - ƚ_{s_i}\right)^{w_i}, \prod_{i=1}^{n} \left(ƥ_{s_i}\right)^{w_i}, \prod_{i=1}^{n} \left(ƫ_{s_i}\right)^{w_i} \right\rangle \tag{10}$$

The Single-Valued Neutrosophic Weighted Aggregation Geometric (SVNWAG) operator for the given set of SVNNs is defined and computed using the following formulation:

$$SVNWGA(\beta_1, \beta_2, \dots, \beta_n) = \prod_{j=1}^{n} \left(\beta_j\right)^{w_j} = \langle \prod_{i=1}^{n} \left(ƚ_{\beta_j}\right)^{w_j}, 1 - \prod_{j=1}^{n} \left(1 - ƥ_{\beta_j}\right)^{w_j}, 1 - \prod_{j=1}^{n} \left(1 - ƫ_{\beta_j}\right)^{w_j} \rangle \tag{11}$$

In this formulation, w_j (j = 1,2,...,n) denotes the weight assigned to each SVNN β_j (j = 1,2,...,n), where $w_j \in [0,1]$ and $\sum_{j=1}^{n} w_j = 1$

Definition 5. Deneutrosophication transforms an SVNN into a corresponding real number. This transformation facilitates decision-making and analysis by reducing the neutrosophic components into a scalar value. Let $\beta = \{ \left(x, ƚ(x), ƥ(x), ƫ(x)\right) \mid x \in ῳ \}$ denoted as SVNN, where $ƚ_\beta$, $ƥ_\beta$, $ƫ_\beta ƫ_A$represent the truth-membership, indeterminacy-membership, and falsity-membership functions, respectively.

To convert this SVNN into a single real value, the following deneutrosophication formula is employed:

$$E = \frac{3 + ƚ_\beta - 2ƥ_\beta - ƫ_\beta}{4} \tag{12}$$

3.3 NS-Delphi Method

Assume a scenario in which *experts evaluate* distinct factors, employing a linguistic scale to express the relative importance of each. These qualitative assessments are subsequently converted into Neutrosophic Set (NS) values. Additionally, experts are assigned weights that reflect their academic qualifications and professional experience. The calculation procedure is outlined as follows:

Step 1. Determining expert weights

To evaluate the influence of each expert, weights are calculated using NS values, which incorporate three principal criteria: the expert's level of education, length of professional experience, and current position within the organization. To evaluate the influence of each expert, NS values are utilized to represent these three criteria, which are then aggregated using Equation (10) to obtain a unified NS score per expert. Finally, these NS scores are consolidated into a single numerical value by applying Equation (12). **Table 6** presents the evaluations conducted by each expert, accompanied by the corresponding linguistic scale used in the assessment process.

Table 6: Expert rating scale

Education	Experience	Position	Linguistic scale	Code	NS number
Doctor	Over 20 years	Executive (CEO, CFO, COO...)	Extremely High	EH	(0.8,0.15,0.2)
Master	From 10 - 20	Senior Management	High	H	(0.6,0.35,0.4)
Bachelor	From 3 - 10	Middle Management	Medium	M	(0.4,0.65,0.6)
Under Bachelor	Less than 3	Administrative/Support Staff	Low	L	(0.2,0.85,0.8)
		Entry-Level Employee	Extremely Low	EL	(0,1,1)

As an illustrative case, Expert 1 holds a master's degree, has 3 to 10 years of professional experience, and currently serves as the organization's Chief Financial Officer (CFO). Based on these credentials, the expert is assessed as "High" (H) for educational background, "Medium" (M) regarding work experience, and "Extremely High" (EH) based on their organizational role. These assessments are represented using NS values: (0.6, 0.35, 0.4) for education, (0.4, 0.65, 0.6) for experience, and (0.8, 0.15, 0.2) for position.

The evaluations are aggregated by applying Equation (10) to derive a unified NS score for Expert 1 as (0.64, 0.32, 0.36). The result is then converted into a crisp value using Equation (12), yielding the expert's final score of 0.6561.

To determine the weight assigned to the g^{th} expert in the group, a set of evaluation scores is first established, denoted as $SG = sg_a = \{sg_1, sg_2, sg_3, \ldots, sg_g\}$. The set of weights assigned to the experts is represented as $SW = sw_a = \{sw_1, sw_2, sw_3, \ldots, sw_g\}$, is then calculated to reflect the relative importance of each expert in the group. These weights are determined using Equation (13):

$$sw_a = \frac{sg_a}{\sum_{a=1}^{g} sg_a} \tag{13}$$

sw_a: The normalized weight of each expert

sg_a: The comprehensive score of each expert

$\sum_{a=1}^{g} sg_a$: The total score of all experts

The outcome indicates the relative significance or influence of that expert in comparison to the other members of the group.

Step 2. Construct an Expert Evaluation Matrix

A panel of g[th] experts evaluates the importance of *n* distinct factors. Their evaluations were expressed through a linguistic scale, then digitized into a neutrosophic number (NSN) based on **Table 7**, and finally converted into the matrix:

$$\otimes F = [f_{ij}]_{n\times g}, \text{ where}$$

n : The total number of factors under assessment

g^{th} : The count of experts involved in the evaluation process

f_{ij}: The element located at row i and column j corresponds to the evaluation provided by expert j for factor i

Table 7: Linguistic Importance Scale in NS-Delphi

Linguistic scale	Code	NS number	Membership function		
			ɬ	ɋ	ŧ
Extremely High	EH	(0.8,0.15,0.2)	0.8	0.15	0.2
High	H	(0.6,0.35,0.4)	0.6	0.35	0.4
Medium	M	(0.4,0.65,0.6)	0.4	0.65	0.6
Low	L	(0.2,0.85,0.8)	0.2	0.85	0.8
Extremely Low	EL	(0,1,1)	0	1	1

Step 3. Compute the threshold and validate the factors

Q experts assess each factor. Initially, their evaluations are aggregated using Equation (10), producing normalized NS representations for *n* factors. These are then converted into crisp scores via Equation (12), yielding a set of *n* evaluation values denoted as $av_i = \{av_1, av_2, \dots, av_n\}$. To determine the acceptance threshold for the evaluated factors, the threshold value ɣ is first calculated. A factor *i* is considered acceptable if its corresponding evaluation score av_i is greater than or equal to ɣ ; otherwise, it is rejected.

The threshold value ɣ is subsequently computed using Equation (14):

$$ɣ = \frac{\sum_{i=1}^{n} av_i}{n} \tag{14}$$

3.4 NS-DEMATEL Method

Assume there are *k* experts, each associated with an individual weight denoted by w_e with $(e = 1,2,\dots,k)$, who is responsible for evaluating the interrelationships among *n* factors. The initial evaluations are articulated using linguistic expressions and then systematically converted into NS values. The mapping between the linguistic terms and their corresponding NS representations is presented in **Table 8.**

Table 8: Linguistic Importance Scale in NS-DEMATEL

Linguistic scale	Code	NS number	Membership function		
			ɬ	ɋ	ŧ
Absolute influence	AI	(0.8,0.15,0.2)	0.8	0.15	0.2
Strong influence	SI	(0.6,0.35,0.4)	0.6	0.35	0.4
Fair influence	FI	(0.4,0.65,0.6)	0.4	0.65	0.6

Weak influence	WI	(0.2,0.85,0.8)	0.2	0.85	0.8
No influence	NI	(0,1,1)	0	1	1

Step 1. Build the Direct Relationship Matrix $\otimes D$

The NS value denotes the influence of factor i on factor j, as perceived by expert e (D_{ij}^{e}). To consolidate the opinions of all experts into a single representative value for each factor pair *(i, j)*. This operation yields the direct relationship matrix, which is applied to each of the three components—truth-membership $\otimes ɟ_D = [ɟ_{ij}]_{n\times n}$, indeterminacy-membership $\otimes ꝑ_D = [ɟ_{ij}]_{n\times n}$, and falsity-membership $\otimes ŧ_D = [ɟ_{ij}]_{n\times n}$—of the neutrosophic number. These three resulting matrices are collectively referred to as $\otimes D = [D_{ij}]_{n\times n}$. It is important to note that no factor is assumed to influence itself; thus, the diagonal elements of the matrix satisfy $\otimes D_{ij} = 0$, when $i = j$

$$D = \begin{bmatrix} 0 & D_{12} & \cdots & D_{1n} \\ D_{21} & 0 & \cdots & D_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ D_{n1} & D_{n2} & \cdots & 0 \end{bmatrix}$$

Step 2. Compute the normalized direct relationship matrix $\otimes S$

A normalized direct-influence matrix is obtained by dividing each element in the direct relationship matrix $\otimes D$ by the maximum row sum of that matrix. To construct the normalized direct relationship matrix $\otimes S$, $\otimes D$ was applied in conjunction with the formulas provided in Equations (15) and (16):

$$\varepsilon = \frac{1}{\max\limits_{1\le i\le n} \sum_{j}^{n} D_{ij}} \tag{15}$$

$$\otimes S = \varepsilon \times D_{ij} \tag{16}$$

Step 3. Calculate the Total Relation Matrix

After obtaining the normalized matrices for each component, at this stage, three separate total influence matrices are constructed, each corresponding to one of the components of the NS number—truth-membership, indeterminacy-membership, and falsity-membership. These matrices are collectively denoted as $\otimes T$

The total relation matrix was obtained using Equation (18):

$$\otimes T = (\otimes S \times I - \otimes S)^{-1} \tag{18}$$

where, $\otimes S$ = normalized matrix, and I = identity matrix

Subsequently, Equation (12) is utilized to transform the NS matrix $\otimes T_{ɟ}$, $\otimes T_{ꝑ}$, $\otimes T_{ŧ}$ into a corresponding matrix of crisp values $\otimes T'$

Step 4. A Causal Diagram

The causal diagram was constructed based on the net cause-and-effect values, where $Ri + Cj$ represents the prominence of each factor, and $Ri - Cj$ indicates the net effect. These values were derived from the total relation matrix $\otimes T'$

In which:

Ri is derived by summing the rows in $\otimes T'$ expressed as $[\otimes Ri]_{n\times 1} = [\sum_{j=1}^{n} t'_{ij}]_{n\times 1}$

$$Ri = \sum_{j=1}^{n} t'_{ij} \text{ for } i = 1,2, \dots, \text{n} \tag{19}$$

Cj is derived by summing the columns in $\otimes T'$ expressed as $[\otimes Cj]_{1\times n} = [\sum_{i=1}^{n} t'_{ij}]_{1\times n}$

$$Cj = \sum_{i=1}^{n} t'_{ij} \text{ for j} = 1,2, \dots, \text{n} \tag{20}$$

When $Ri - Cj$ yields a positive value, the corresponding factor is classified as a Cause, meaning it exerts influence on other factors. Conversely, a negative value of $Ri - Cj$ indicates that the factor is an Effect, suggesting it is primarily influenced by other factors within the system.

The quantity $Ri + Cj$ signifies the prominence of a given factor, encapsulating the total degree to which the factor is involved in the system. In essence, it reflects the overall impact of the indicator, accounting for both the influence it imposes on and receives from other factors. Thus, Equation (21) will calculate the indicator's impact weight.

$$\theta_i = \frac{(Ri + Cj)}{\sum_{i=1}^{n}(Ri + Cj)} \tag{21}$$

3.5 NS-WASPAS method

The NS-WASPAS method adapts the classical WASPAS approach by representing decision criteria and weights as single-valued neutrosophic numbers. The process involves the following steps and equations:

Step 1. Neutrosophic Decision Matrix:

For (m) alternatives and (n) criteria, the decision matrix (X) contains neutrosophic values $X_{ij} = (ƚ_{ij},\ ꝑ_{ij},\ ŧ_{ij})$ for alternative (i) and criterion (j). Criteria weights are also neutrosophic, denoted $w_j = (ƚ_{w_j}, ꝑ_{w_j}, ŧ_{w_j})$.

Step 2. Weighted Sum Model (WSM):

The neutrosophic weighted sum score for alternative (i) is calculated using Equation (22):

$$\mathbb{Q}_i^{(1)} = \bigoplus_{j=1}^{n} w_j \varsigma_{ij}. \tag{22}$$

Where $\oplus$ denotes neutrosophic multiplication, combining truth, indeterminacy, and falsity components.

Step 3. Weighted Product Model (WPM):

The neutrosophic weighted product score for alternative (i) is calculated using Equation (23), involving neutrosophic exponentiation.

$$\mathbb{Q}_i^{(2)} = \otimes_{j=1}^{n} w_j \varsigma_{ij}. \tag{23}$$

Step 4. NS-WASPAS Score:

The final score combines WSM and WPM using a balancing parameter (ϑ [0,1]) (typically ϑ = 0.5) for equal weighting) using Equation (24).

$$\mathbb{Q}_i = \vartheta \mathbb{Q}_i^{(1)} + (1-\vartheta)\mathbb{Q}_i^{(2)}, \tag{24}$$

The neutrosophic scores $\mathbb{Q}_i$= ($f_{\mathbb{Q}_i}$, $p_{\mathbb{Q}_i}$, $t_{\mathbb{Q}_i}$) are then de-neutrosophic (e.g., using a score function Equation(12) to rank alternatives, with higher scores indicating better strategies.

4. Results

4.1 Expert Selection and Expert's Weight

To ensure robust and reliable input for the study, a panel of 50 experts in HLM in Vietnam was selected based on their expertise, experience, and professional roles. The demographic profile of the experts, summarized in **Table 9**, reflects diversity in age, gender, education, position, and years of experience, ensuring a comprehensive range of perspectives.

Table 9: NS-Delphi linguistic significant scale

Demographic	Sematic	Count	%
Age	Under 25	21	42%
	From 25 to 40	11	22%
	From 40 to 60	14	28%
	Over 60	8	8%
Gender	Male	25	50%
	Female	22	44%
	Prefer not to say	3	6%
Education	Doctor	9	18%
	Master	17	34%
	Bachelor	20	40%
	Under Bachelor	4	8%
Position	Executive	9	18%
	Senior Management	12	24%
	Middle Management	10	20%
	Administrative/Support Staff	13	26%
	Entry-Level Employee	6	12%
Experience	Over 20 years	7	14%
	From 10 to 20 years	12	24%
	From 3-10 years	20	40%
	Less than 3 years	11	22%

Expert weights were determined by incorporating education, experience, and position to assign neutrosophic evaluation values representing truth, indeterminacy, and falsity degrees. The score function converted these values to crisp values, and normalized weights were calculated. **Table 10** presents experts' weights, with higher weights assigned to experts with advanced education, extensive experience, and senior positions.

Table 10: Expert's Weight

Expert	Education	Experience	Position	Evaluation Value (EV)	Crips Value	Weight
Expert 1	Master	From 10 - 20 years	Executive (CEO, CFO, COO...)	(0.6825,0.2639,0.3175)	0.7093	0.0297

Expert 2	Bachelor	From 3 - 10 years	Administrative/Support Staff	(0.3396,0.7108,0.6604)	0.3144	0.0132
Expert 3	Bachelor	From 3 - 10 years	Entry-Level Employee	(0.2886,0.7504,0.7114)	0.2691	0.0113
Expert 4	Master	From 10 - 20 years	Executive (CEO, CFO, COO...)	(0.6825,0.2639,0.3175)	0.7093	0.0297
Expert 5	Master	Less than 3 years	Entry-Level Employee	(0.3160,0.6676,0.6840)	0.3242	0.0136
Expert 6	Master	Over 20 years	Senior Management	(0.6825,0.2639,0.3175)	0.7093	0.0297
Expert 7	Doctor	Over 20 years	Executive (CEO, CFO, COO...)	(0.8,0.15,0.2)	0.825	0.0346
Expert 8	Bachelor	From 3 - 10 years	Senior Management	(0.4759,0.5288,0.5241)	0.4735	0.0199
Expert 9	Doctor	From 10 - 20 years	Senior Management	(0.6825,0.2639,0.3175)	0.7093	0.0297
Expert 10	Master	From 3 - 10 years	Executive (CEO, CFO, COO...)	(0.6366,0.3244,0.3634)	0.6561	0.0275
Expert 11	Bachelor	Less than 3 years	Entry-Level Employee	(0.2170,0.8206,0.7830)	0.1982	0.0083
Expert 12	Bachelor	From 3 - 10 years	Administrative/Support Staff	(0.3396,0.7108,0.6604)	0.3144	0.0132
Expert 13	Master	From 3 - 10 years	Senior Management	(0.5421,0.4302,0.4579)	0.556	0.0233
Expert 14	Bachelor	From 10 - 20 years	Middle Management	(0.4759,0.5288,0.5241)	0.4735	0.0199
Expert 15	Bachelor	Less than 3 years	Administrative/Support Staff	(0.2732,0.7773,0.7268)	0.2479	0.0104
Expert 16	Master	From 10 - 20 years	Senior Management	(0.6,0.35,0.4)	0.625	0.0262
Expert 17	Bachelor	From 3 - 10 years	Executive (CEO, CFO, COO...)	(0.5840,0.3987,0.4160)	0.5926	0.0248
Expert 18	Bachelor	From 3 - 10 years	Administrative/Support Staff	(0.3396,0.7108,0.6604)	0.3144	0.0132
Expert 19	Doctor	From 10 - 20 years	Administrative/Support Staff	(0.6,0.3547,0.4)	0.6227	0.0261
Expert 20	Master	Over 20 years	Executive (CEO, CFO, COO...)	(0.7480,0.1990,0.2520)	0.7745	0.0325
Expert 21	Bachelor	From 3 - 10 years	Middle Management	(0.4,0.65,0.6)	0.375	0.0157
Expert 22	Bachelor	From 3 - 10 years	Middle Management	(0.4,0.65,0.6)	0.375	0.0157
Expert 23	Doctor	Over 20 years	Executive (CEO, CFO, COO...)	(0.8,0.15,0.2)	0.825	0.0346
Expert 24	Master	Over 20 years	Senior Management	(0.6825,0.2639,0.3175)	0.7093	0.0297
Expert 25	Under Bachelor	Less than 3 years	Entry-Level Employee	(0.1382,0.8973,0.8618)	0.1205	0.0051
Expert 26	Bachelor	Less than 3 years	Middle Management	(0.3396,0.7108,0.6604)	0.3144	0.0132
Expert 27	Bachelor	Less than 3 years	Administrative/Support Staff	(0.2732,0.7773,0.7268)	0.2479	0.0104
Expert 28	Doctor	From 10 - 20 years	Executive (CEO, CFO, COO...)	(0.7480,0.1990,0.2520)	0.7745	0.0325
Expert 29	Bachelor	Less than 3 years	Administrative/Support Staff	(0.2732,0.7773,0.7268)	0.2479	0.0104
Expert 30	Under Bachelor	From 3 - 10 years	Middle Management	(0.3396,0.7108,0.6604)	0.3144	0.0132
Expert 31	Bachelor	Less than 3 years	Administrative/Support Staff	(0.2732,0.7773,0.7268)	0.2479	0.0104
Expert 32	Master	From 10 - 20 years	Senior Management	(0.6,0.35,0.4)	0.625	0.0262
Expert 33	Under Bachelor	From 3 - 10 years	Senior Management	(0.4231,0.5783,0.5769)	0.4224	0.0177
Expert 34	Bachelor	From 3 - 10 years	Middle Management	(0.4,0.65,0.6)	0.375	0.0157
Expert 35	Bachelor	From 3 - 10 years	Middle Management	(0.4,0.65,0.6)	0.375	0.0157
Expert 36	Bachelor	Less than 3 years	Executive (CEO, CFO, COO...)	(0.5421,0.4360,0.4579)	0.5531	0.0232
Expert 37	Master	From 3 - 10 years	Administrative/Support Staff	(0.4231,0.5783,0.5769)	0.4224	0.0177
Expert 38	Master	From 3 - 10 years	Administrative/Support Staff	(0.4231,0.5783,0.5769)	0.4224	0.0177
Expert 39	Master	From 10 - 20 years	Administrative/Support Staff	(0.4960,0.4705,0.5040)	0.5128	0.0215
Expert 40	Doctor	Over 20 years	Senior Management	(0.7480,0.1990,0.2520)	0.7745	0.0325
Expert 41	Under Bachelor	Less than 3 years	Entry-Level Employee	(0.1382,0.8973,0.8618)	0.1205	0.0051
Expert 42	Master	Over 20 years	Senior Management	(0.6825,0.2639,0.3175)	0.7093	0.0297
Expert 43	Master	From 10 - 20 years	Senior Management	(0.6000,0.3500,0.4000)	0.625	0.0262
Expert 44	Bachelor	From 3 - 10 years	Administrative/Support Staff	(0.3396,0.7108,0.6604)	0.3144	0.0132
Expert 45	Doctor	From 10 - 20 years	Senior Management	(0.6825,0.2639,0.3175)	0.7093	0.0297
Expert 46	Master	From 3 - 10 years	Middle Management	(0.4759,0.5288,0.5241)	0.4735	0.0199
Expert 47	Master	From 10 - 20 years	Middle Management	(0.5421,0.4302,0.4579)	0.556	0.0233
Expert 48	Bachelor	Less than 3 years	Entry-Level Employee	(0.2170,0.8206,0.7830)	0.1982	0.0083
Expert 49	Bachelor	From 3 - 10 years	Middle Management	(0.4,0.65,0.6)	0.375	0.0157
Expert 50	Bachelor	From 3 - 10 years	Administrative/Support Staff	(0.3396,0.7108,0.6604)	0.3144	0.0132

4.2 NS-Delphi Results

The NS-Delphi method validated the 50 CSFs identified for HLM in Vietnam. Experts assessed each CSF's relevance using a neutrosophic linguistic scale. A consensus threshold of crisp value ≥ 0.02 (derived from the score function) was set to ensure reliability. The results, summarized in **Table 11**, highlight the validated and excluded CSFs, providing a refined list for further analysis in Phase 2.

Among them, the outstanding factors with the highest crisp values include OF10 - Real-Time Monitoring and Tracking (0.7415), SF1 - Government Policy and Regulations (0.7360), and TF10 - Satellite and GIS for Route Optimization (0.6983). This shows that real-time monitoring and tracking capabilities, support from government policies and laws, and applying satellite technology and geographic information systems (GIS) in route optimization are fundamental factors that profoundly impact logistics operations efficiency. Specifically, OF10 – Real-Time Monitoring and Tracking is considered a key factor in improving the responsiveness and transparency of the supply chain by providing instant data to stakeholders. SF1 – Government Policy and Regulations guide and create the necessary legal corridor, encourage investment, the application of new technology, and sustainable development. Meanwhile, TF10 – Satellite and GIS for Route Optimization demonstrates the importance of applying high technology to optimize operating costs, shorten delivery times, and reduce environmental impact. In contrast, some factors such as OF6 – Cold Chain Logistics (0.3796), SF8 – Legal and Institutional Frameworks (0.6476), TF2 – Big Data Analytics for Decision-Making (0.6436), TF8 – Cybersecurity for Data Protection (0.6186), FF5 – Insurance Mechanisms for Logistics Operations (0.6218), EF3 – Sustainable Resource Management (0.6000) and EF8 – Gender-Inclusive Disaster Logistics Planning (0.5694) did not pass the validation threshold, indicating a lower level of consensus and unclear role in the research context. Specifically, in the group of Strategic factors (SF), factor SF8 - Legal and Institutional Frameworks was not confirmed, showing that the current legal and institutional framework is not considered a top priority factor in improving HLM efficiency at present, possibly because the legal system is still in the process of being completed or has not had a clear impact on operational efficiency. For the group of Operational factors (OF), OF6 - Cold Chain Logistics is the only factor that was not confirmed. This shows that the cold chain is not considered essential in all logistics sectors, and its implementation is still limited and uneven in Vietnam. In the Technological factors (TF) group, TF2 - Big Data Analytics for Decision-Making and TF8 - Cybersecurity for Data Protection were not confirmed. Although. Big data technology and cybersecurity are global trends, but the current infrastructure, capacity, and awareness in logistics may not be sufficient to promote these two factors effectively. For the Financial and Resource Management Factors (FF) group, FF5 - Insurance Mechanisms for Logistics Operations did not pass the threshold, showing that logistics insurance has not received due attention and has not yet played an essential role in minimizing financial risks. Finally, in the Social & Environmental Factors (EF) group, the two factors EF3 - Sustainable Resource Management and EF8 - Gender-Inclusive Disaster Logistics Planning were not confirmed. The reason is that sustainable strategies and gender equality approaches in disaster logistics are still new and not widely applied, so experts have not evaluated them as important factors in the current period.

Table 11: The NS-Delphi Results

CSFs	Aggregate	Crips	Validate	CSFs	Aggregate	Crips	Validate
SF1	(0.71254,0.24045,0.28746)	0.73604261	Yes	**TF6**	(0.65414,0.30049,0.34586)	0.67682061	Yes
SF2	(0.68480,0.26954,0.31520)	0.70762966	Yes	**TP7**	(0.66342,0.28988,0.33658)	0.6867695	Yes
SF3	(0.65355,0.30030,0.34645)	0.67662821	Yes	**TF8**	(0.59986,0.36258,0.40014)	0.618639	No
SF4	(0.65830,0.29638,0.34170)	0.68095998	Yes	**TF9**	(0.65676,0.29707,0.34324)	0.67984652	Yes
SF5	(0.66531,0.29142,0.33469)	0.68694376	Yes	**TF10**	(0.67503,0.27833,0.32497)	0.69835165	Yes
SF6	(0.65478,0.30146,0.34522)	0.67666424	Yes	**FF1**	(0.66606,0.28691,0.33394)	0.68957242	Yes
SF7	(0.65478,0.29959,0.34522)	0.67759498	Yes	**FF2**	(0.65121,0.30677,0.34879)	0.67222083	Yes
SF8	(0.62792,0.33271,0.37208)	0.64760604	No	**FF3**	(0.67035,0.28378,0.32965)	0.69328261	Yes
SF9	(0.66090,0.29490,0.33910)	0.68299797	Yes	**FF4**	(0.66676,0.28672,0.33324)	0.69002335	Yes
SF10	(0.65690,0.30099,0.34310)	0.67795563	Yes	**FF5**	(0.60221,0.35857,0.39779)	0.62181987	No
OF1	(0.66708,0.28707,0.33292)	0.69000771	Yes	**FF6**	(0.67182,0.28058,0.32818)	0.69562022	Yes
OF2	(0.65947,0.29671,0.34053)	0.68137803	Yes	**FF7**	(0.65161,0.30337,0.34839)	0.67412177	Yes
OF3	(0.65442,0.29996,0.34558)	0.67723146	Yes	**FF8**	(0.67366,0.27902,0.32634)	0.69731856	Yes
OF4	(0.65297,0.30285,0.34703)	0.6750606	Yes	**FF9**	(0.66982,0.28565,0.33018)	0.69208563	Yes
OF5	(0.65083,0.30615,0.34917)	0.67234262	Yes	**FF10**	(0.65584,0.30025,0.34416)	0.67779302	Yes
OF6	(0.38143,0.62214,0.61857)	0.37964433	No	**EF1**	(0.65238,0.30191,0.34762)	0.67523664	Yes
OF7	(0.65756,0.29609,0.34244)	0.68073833	Yes	**EF2**	(0.65931,0.29844,0.34069)	0.6804317	Yes
OF8	(0.65024,0.30721,0.34976)	0.67151529	Yes	**EF3**	(0.58379,0.38371,0.41621)	0.60004043	No
OF9	(0.65431,0.29916,0.34569)	0.67757568	Yes	**EF4**	(0.65276,0.30354,0.34724)	0.67460895	Yes
OF10	(0.71678,0.23368,0.28322)	0.74154895	Yes	**EF5**	(0.67587,0.27657,0.32413)	0.69965043	Yes
TF1	(0.65882,0.29778,0.34118)	0.68052253	Yes	**EF6**	(0.65118,0.30496,0.34882)	0.67311355	Yes
TF2	(0.62369,0.33640,0.37631)	0.6436474	No	**EF7**	(0.65621,0.29967,0.34379)	0.67826927	Yes
TF3	(0.65529,0.30128,0.34471)	0.67700638	Yes	**EF8**	(0.55591,0.41705,0.44409)	0.56943094	No
TF4	(0.65142,0.30517,0.34858)	0.67312647	Yes	**EF9**	(0.67855,0.27378,0.32145)	0.70238801	Yes
TF5	(0.66562,0.28763,0.33438)	0.68899488	Yes	**EF10**	(0.65517,0.30257,0.34483)	0.67630331	Yes
	Threshold					**0.02**	

4.3 NS-DEMATEL Results

Following the NS-Delphi phase, 43 CSFs were validated for HLM in Vietnam. The NS-DEMATEL method was applied to analyze their cause-and-effect relationships, assessing how each CSF influences others. The results, detailed in **Tables 12-17**, provide insights into the interdependencies shaping effective HLM strategies. The process began with constructing a direct-relation matrix based on expert assessments, using a linguistic scale ranging from "No influence" to "Absolute influence." This matrix was converted into a Neutrosophic direct-relation matrix by mapping linguistic terms to single-valued neutrosophic numbers. Inputs from 50 experts ensured accuracy and reliability.

4.3.1 NS-DEMATEL Main Dimensions Results

The NS-DEMATEL analysis, as presented in **Table 14** and **Figure 3**, provides a comprehensive view of the interactions among the five key dimensions of HLM: Strategic Factors (SF), Operational Factors (OF), Technological Factors (TF), Financial and Resource Management Factors (FF), and Social & Environmental Factors (EF). **Table 14** shows that SF has the highest prominence ($R_i + C_i$ = 4.7477) and weight (0.21), ranking first, highlighting its central role in coordinating HLM through policies, decision-making, and governance [133]. However, with ($R_i - C_i$= -0.1197), SF is an "effect" factor heavily influenced by other dimensions, as confirmed by Figure 3, where SF receives strong impacts from TF (0.4807) and FF (0.4813). In contrast, TF ($R_i - C_i$ = 0.0544, prominence 4.5306, rank 2) and FF ($R_i - C_i$= 0.0991, prominence 4.5303, rank 3) are "cause" factors exerting significant influence across the system.

Table 14: The NS-DEMATEL Results of Main Dimensions

CSFs	R_i	C_i	$R_i + C_i$	$R_i - C_i$	Weight	Rank	Identify
SF	2.314	2.4337	4.7477	-0.1197	0.21	1	Effect
OF	2.257	2.2693	4.5263	-0.0123	0.2002	4	Effect
TF	2.2925	2.2381	4.5306	0.0544	0.2004	2	Cause
FF	2.3147	2.2156	4.5303	0.0991	0.2003	3	Cause
EF	2.1284	2.1498	4.2782	-0.0214	0.1892	5	Effect

Figure 3 further illustrates their roles, with TF strongly affecting SF (0.4807) and OF (0.4563), enabling rapid and transparent relief operations through technologies like humanitarian information systems and AI [103]. At the same time, FF impacts SF (0.4813), OF (0.4506), and EF (0.4258), supporting social initiatives and sustainability through effective resource allocation. OF, with $R_i - C_i$= -0.0123, a prominence of 4.5263, and a rank of 4 acts as a mediator, influenced by TF (0.4563) and FF (0.4506) but impacting SF (0.4668), though its effect on EF is weak (0.4031). EF, with the lowest prominence ($R_i + C_i$= 4.2782) and $R_i - C_i$ = -0.0214, ranks last (5) as an "effect" factor, showing limited influence (e.g., EF → OF = 0.3800, EF → TF = 0.4039) despite receiving moderate impacts from FF (0.4258) and TF (0.4218). Although social and environmental aspects like community consensus and climate change are practically significant, their integration into HLM decision-making remains limited. These findings emphasize the critical role of TF and FF as system levers, urging humanitarian organizations to prioritize technological and financial capacities while enhancing EF integration to build a more responsive, flexible, and sustainable HLM system amidst global challenges.

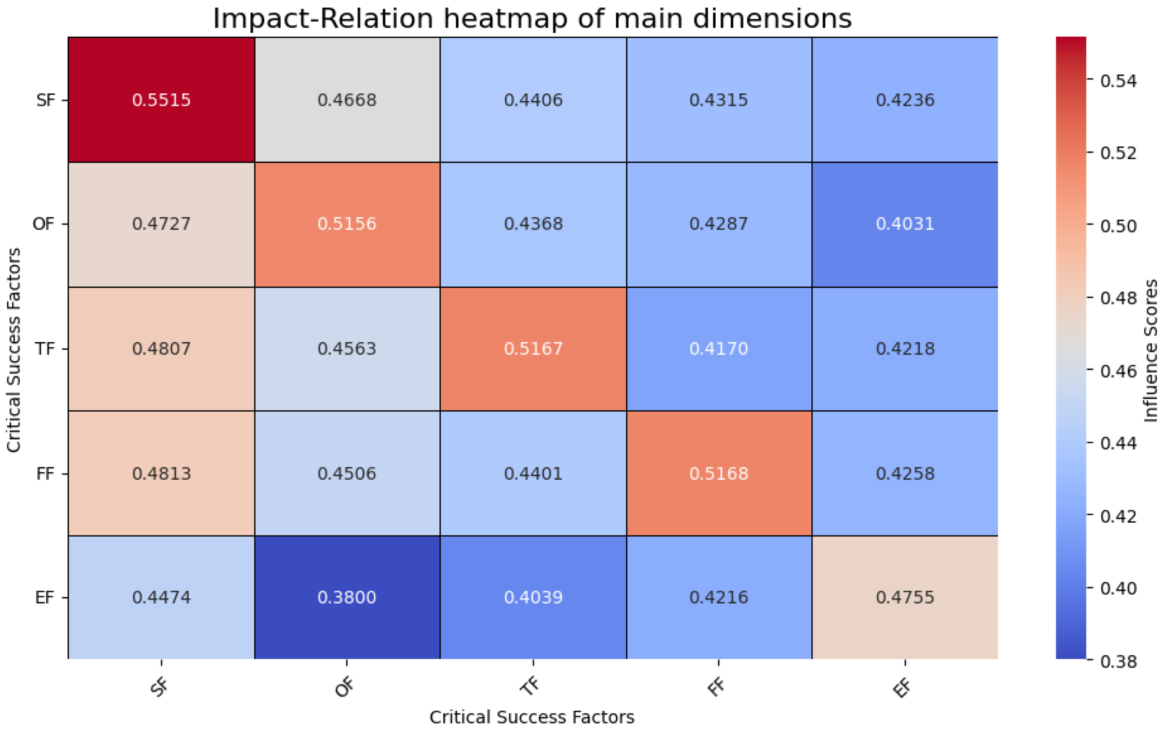

Figure 3: Impact-Relation heatmap of main dimensions

4.3.2 NS-DEMATEL Strategic Factors (SF) Result

The NS-DEMATEL analysis of Strategic Factors in HLM in Vietnam, as presented in **Table 15** and **Figure 4**, reveals a clear hierarchical structure of roles and influences among the factors (SF1 to SF10). **Table 15** shows that SF3 has the highest prominence ($R_i + C_i$ = 8.7176) and weight (0.1179), ranking first, emphasizing the critical need for proactive forecasting and preparedness actions given Vietnam's high frequency of natural disasters. However, with $R_i - C_i$= -0.0532, SF3 is an "effect" factor, indicating its dependence on other drivers. SF1 ($R_i + C_i$= 8.4404, rank 2) and SF2 ($R_i + C_i$= 8.2435, rank 4) also exhibit high prominence but are "effect" factors ($R_i - C_i$= -0.0642 and -0.1737, respectively), suggesting that policies and coordination frameworks rely on drivers like funding, technology, and networks. In contrast, SF6 ($R_i - C_i$= 0.4457, prominence 8.3959, rank 3) and SF9 ($R_i - C_i$= 0.3535, prominence 8.1565, rank 5) are "cause" factors, highlighting the pivotal role of community mobilization, the private sector, and international support in enhancing HLM effectiveness. SF5 ($R_i - C_i$= -0.2076, rank 6), SF7 ($R_i - C_i$= -0.1199, rank 7), SF4 ($R_i - C_i$= -0.047, rank 8), and SF10 ($R_i - C_i$= -0.1336, rank 9) are all "effect" factors, indicating their reactive nature and dependence on strategic resources.

Table 15: The NS-DEMATEL of Strategic Factors Results

CSFs	R_i	C_i	$R_i + C_i$	$R_i - C_i$	Weight	Rank	Identify
SF1	4.1881	4.2523	8.4404	-0.0642	0.1142	2	Effect
SF2	4.0349	4.2086	8.2435	-0.1737	0.1115	4	Effect
SF3	4.3322	4.3854	8.7176	-0.0532	0.1179	1	Effect
SF4	3.9827	4.0297	8.0124	-0.047	0.1084	8	Effect
SF5	3.9543	4.1619	8.1162	-0.2076	0.1098	6	Effect
SF6	4.4208	3.9751	8.3959	0.4457	0.1136	3	Cause

SF7	3.9584	4.0783	8.0367	-0.1199	0.1087	7	Effect
SF9	4.255	3.9015	8.1565	0.3535	0.1103	5	Cause
SF10	3.8383	3.9719	7.8102	-0.1336	0.1056	9	Effect

Figure 4, the Impact-Relation Heatmap, further illustrates these dynamics, with influence scores ranging from 0.3964 (weakest) to 0.5461 (strongest), excluding self-interactions. SF3 exerts strong influences on SF6 (0.5461) and SF9 (0.5044), reflecting its significant yet dependent role, while SF6 strongly impacts SF3 (0.5170) and SF9 (0.4933), confirming its role as a key driver. SF9 also notably influences SF3 (0.5044) and SF6 (0.4573), reinforcing its causal role. SF1, SF2, and SF5 receive moderate influences (e.g., SF6 → SF1 = 0.5043, SF9 → SF2 = 0.4789), shown in reddish-pink tones, while SF4, SF7, and SF10 exhibit weaker influences (e.g., SF10 → SF9 = 0.3964, SF4 → SF10 = 0.4147), indicated by light blue shades, confirming their supportive roles. The analysis underscores the need to prioritize systemic root causes like SF6 and SF9 to enhance strategic performance in Vietnam's HLM while shifting policy-making from passive to proactive approaches, integrating cross-sectoral coordination among government, civil society, and international organizations to build resilient disaster response capacities.

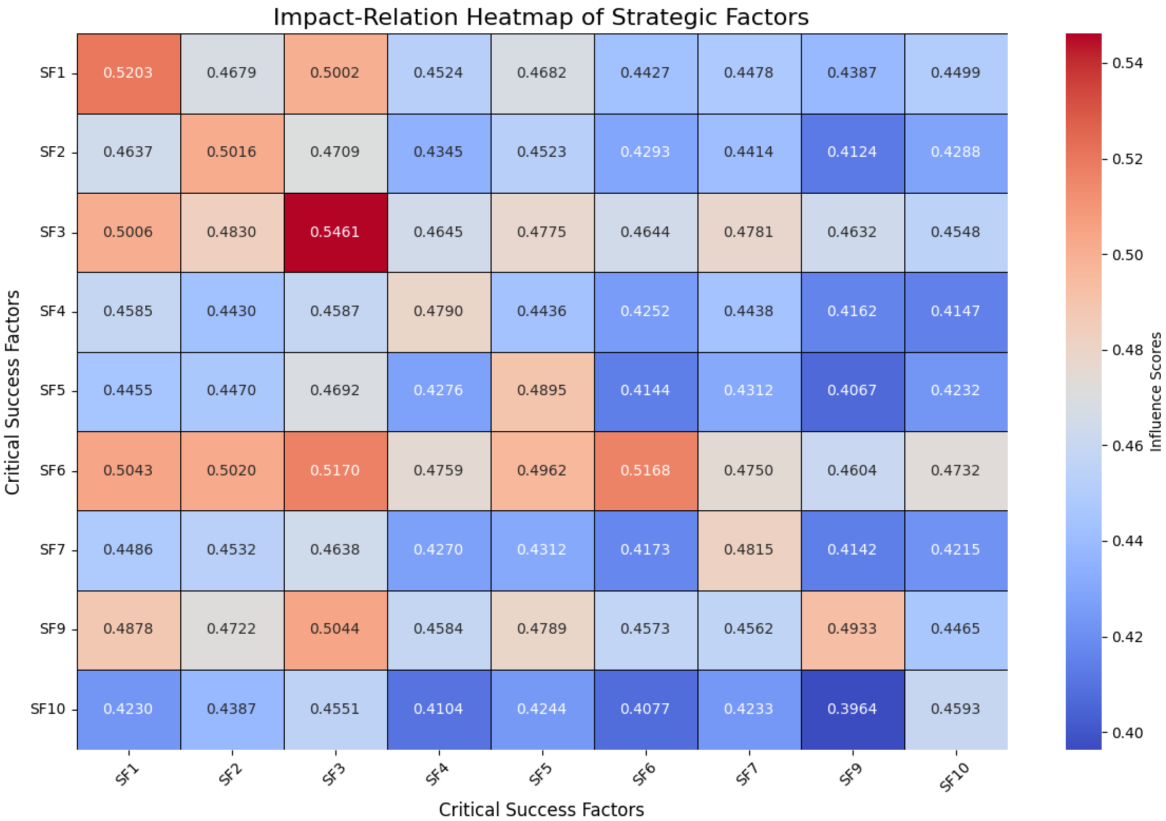

Figure 4: Impact-Relation Heatmap of Strategic Factors

4.3.3 NS-DEMATEL Operational Factors (OF) Results

The NS-DEMATEL analysis of Operational Factors in humanitarian logistics management in Vietnam, as detailed in **Table 16** and **Figure 5**, elucidates the interdependencies among the factors (OF1 to OF10). **Table 16** indicates that OF3 has the highest prominence ($R_i + C_i$ = 8.0855) and weight (0.1146), ranking first, but with $R_i - C_i$ = -0.2167, it is the most affected "effect" factor, reflecting its high dependency on other operational factors. OF4 ($R_i + C_i$= 8.0556, $R_i - C_i$ = -0.1276, rank 2) and OF1 ($R_i + C_i$= 8.0414, $R_i - C_i$= -0.1932, rank 3) are also "effect" factors, identifying them as bottlenecks that require strengthening to enhance rapid response capabilities during crises. OF2 ($R_i + C_i$ = 7.793, $R_i - C_i$= -0.166, rank 6) exhibits a medium impact but plays a connecting role in multi-organizational coordination. Conversely, OF9 ($R_i - C_i$= 0.2595, prominence 7.7973, rank 5), OF10 ($R_i - C_i$= 0.209, prominence 7.7528, rank 8), OF8 ($R_i - C_i$= 0.065, prominence 7.765, rank 7), OF7 ($R_i - C_i$= 0.127, prominence 7.2798, rank 9), and OF5 ($R_i - C_i$= 0.043, prominence 7.9796, rank 4) are "cause" factors, with OF9 and OF10 showing the strongest proactive roles, indicating their potential to impact the system if prioritized positively. OF5 supports supply chain stability, while OF8 requires synchronization for consistent emergency responses, and OF7 underscores the importance of human resource development in enhancing other factors.

Table 16: The NS-DEMATEL Operational Factors Results

CSFs	R_i	C_i	$R_i + C_i$	$R_i - C_i$	Weight	Rank	Identify
OF1	3.9241	4.1173	8.0414	-0.1932	0.114	3	Effect
OF2	3.8135	3.9795	7.793	-0.166	0.1105	6	Effect
OF3	3.9344	4.1511	8.0855	-0.2167	0.1146	1	Effect
OF4	3.964	4.0916	8.0556	-0.1276	0.1142	2	Effect
OF5	4.0113	3.9683	7.9796	0.043	0.1131	4	Cause
OF7	3.7034	3.5764	7.2798	0.127	0.1032	9	Cause
OF8	3.915	3.85	7.765	0.065	0.1101	7	Cause
OF9	4.0284	3.7689	7.7973	0.2595	0.1105	5	Cause
OF10	3.9809	3.7719	7.7528	0.209	0.1099	8	Cause

Figure 5, the Impact-Relation Heatmap, with influence scores from 0.3832 (weakest) to 0.5025 (strongest), excluding self-interactions, further highlights these dynamics. OF3 receives strong influences from OF9 (0.4804) and OF10 (0.4604), confirming its dependency, while OF9 strongly impacts OF3 (0.4804) and OF5 (0.4460), and OF10 influences OF3 (0.4604) and OF5 (0.4469), reinforcing their causal roles. OF1, OF4, and OF5 experience moderate influences (e.g., OF9 → OF1 = 0.4660, OF10 → OF4 = 0.4599), shown in orange tones, while OF7 and OF8 exhibit weaker impacts (e.g., OF7 → OF8 = 0.3969, OF8 → OF7 = 0.3832), indicated by blue shades. The analysis reveals that "effect" factors (OF1, OF3, OF4) are tied to infrastructure and downstream functions. In contrast, "cause" factors (OF9, OF10, OF7) relate to strategy, technology, and human capacity, suggesting that investing in these proactive factors can enhance the adaptability and resilience of Vietnam's humanitarian logistics system.

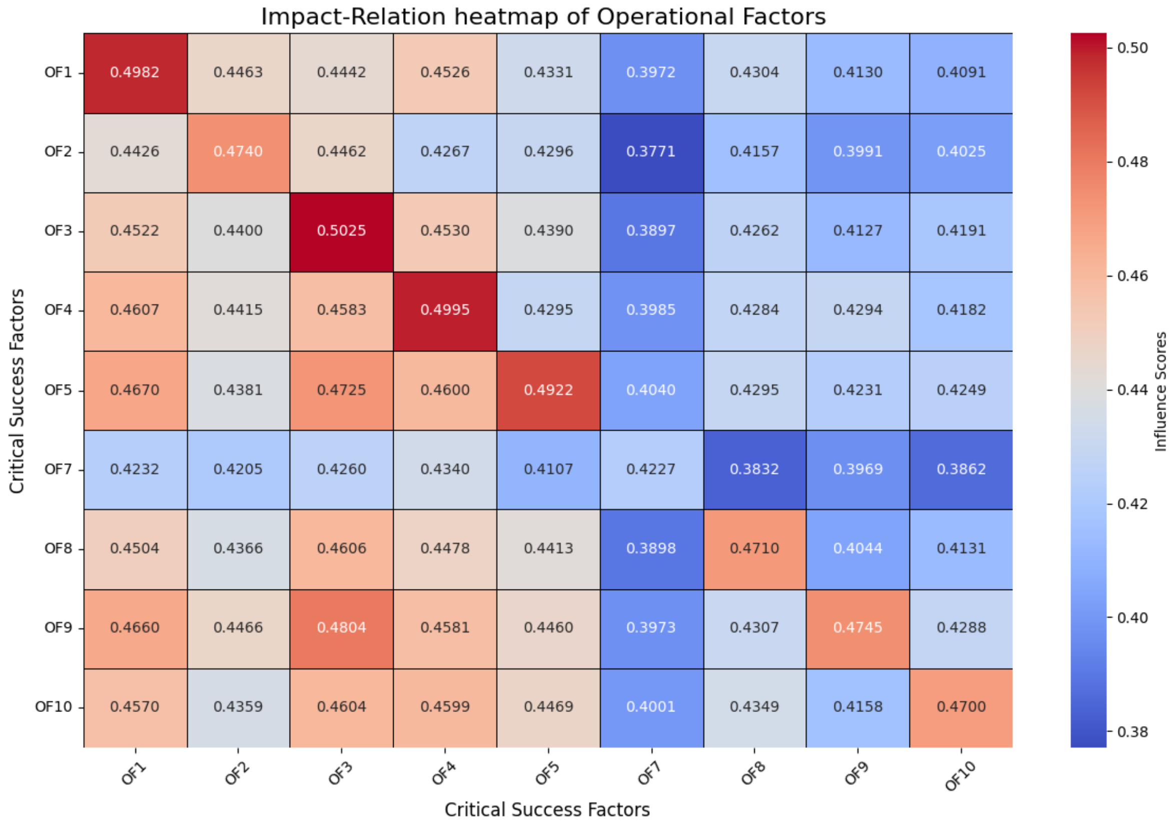

Figure 5: Impact-Relation Heatmap of Operational Factors

4.3.4 NS-DEMATEL Technological Factors (TF) Results

As presented in **Table 17** and **Figure 6**, Technological factors play a key role in improving the effectiveness of HLM in the context of natural disasters in Vietnam. **Table 17** shows that TF7 is the most prominent factor ($R_i + C_i$= 8.453, weight 0.1296, rank 1) and a "cause" factor ($R_i - C_i$= 0.0158), reflecting the urgent need for a sustainable logistics system adaptable to complex disasters. TF10 ($R_i - C_i$= 0.3698, prominence 8.223, rank 3), TF3 ($R_i - C_i$= 0.0145, prominence 8.3553, rank 2), TF1 ($R_i - C_i$= 0.1057, prominence 8.1185, rank 5), and TF9 ($R_i - C_i$= 0.058, prominence 7.9394, rank 7) are also "cause" factors, with TF10 and TF1 supporting transparency and resource optimization, key in contexts with limited funding and the need for rapid distribution. In contrast, TF6 ($R_i - C_i$= -0.4451, prominence 7.8727, rank 8), TF5 ($R_i - C_i$= -0.0786, prominence 8.2186, rank 4), and TF4 ($R_i - C_i$= -0.0401, prominence 8.0273, rank 6) are "effect" factors heavily influenced by the broader system, indicating that technological resources struggle to be effective in Vietnam's disaster response without clear direction and robust management tools.

Table 17: The NS-DEMATEL Technological Factors Results

CSFs	R_i	C_i	$R_i + C_i$	$R_i - C_i$	Weight	Rank	Identify
TF1	4.1121	4.0064	8.1185	0.1057	0.1245	5	Cause
TF3	4.1849	4.1704	8.3553	0.0145	0.1281	2	Cause
TF4	3.9936	4.0337	8.0273	-0.0401	0.1231	6	Effect
TF5	4.07	4.1486	8.2186	-0.0786	0.126	4	Effect
TF6	3.7138	4.1589	7.8727	-0.4451	0.1207	8	Effect
TF7	4.2344	4.2186	8.453	0.0158	0.1296	1	Cause
TF9	3.9987	3.9407	7.9394	0.058	0.1218	7	Cause

TF10	4.2964	3.9266	8.223	0.3698	0.1261	3	Cause

Figure 6, the Impact-Relation Heatmap, with influence scores from 0.4344 (weakest) to 0.5866 (strongest), excluding self-interactions, further illustrates these dynamics. TF7 strongly influences TF6 (0.5866) and TF10 (0.5181), reinforcing its proactive role, while TF10 impacts TF6 (0.5640) and TF7 (0.5181), and TF3 affects TF1 (0.5764) and TF5 (0.5229), confirming their causal roles. TF6, TF5, and TF4 receive moderate to strong influences (e.g., TF7 → TF6 = 0.5866, TF10 → TF5 = 0.5363), shown in reddish tones, while TF9 and TF1 exhibit moderate impacts (e.g., TF9 → TF10 = 0.4792, TF1 → TF3 = 0.5144), indicated by lighter shades. The analysis underscores that prioritizing investments in proactive factors like TF7, TF10, and TF3 can establish a robust technological foundation for HLM, enhancing response capacity and supporting communities more effectively during emergencies in Vietnam.

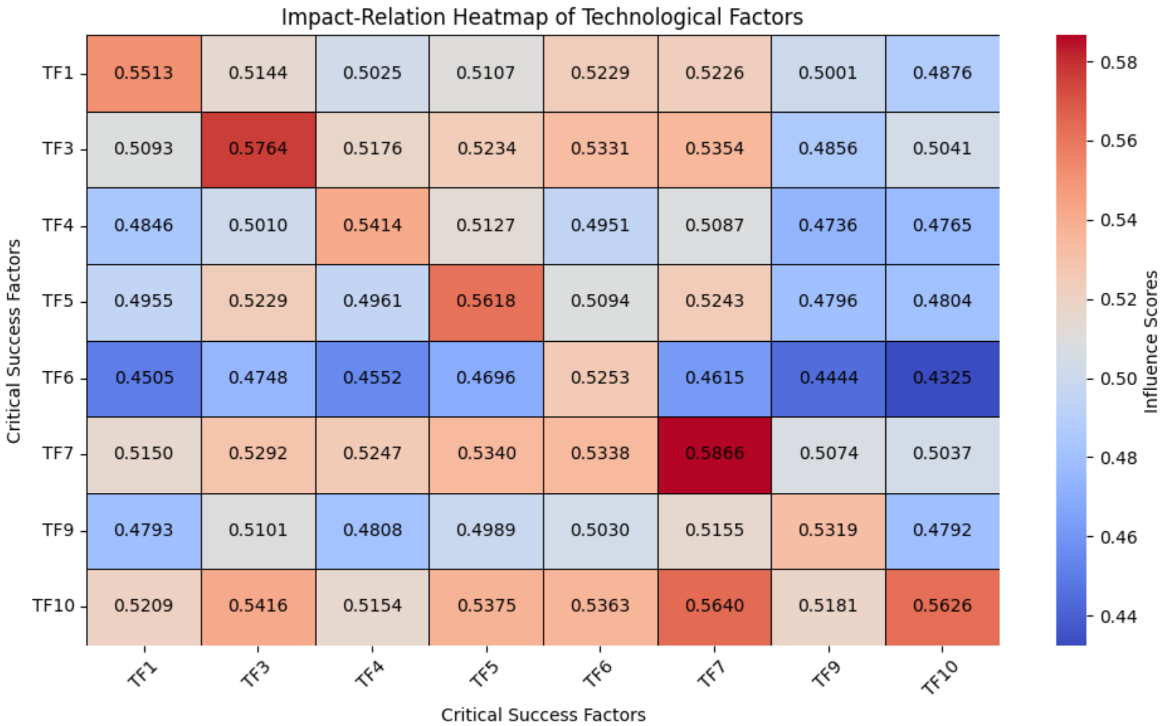

Figure 6: Impact-Relation Heatmap of Technological Factors

4.3.5 NS-DEMATEL Financial and Resources Factors (FF) Results

Table 18 shows that FF7 is the most prominent factor ($R_i + C_i$ = 8.8211, weight 0.1153, rank 1) and a "cause" factor ($R_i - C_i$= 0.4461), indicating its primary role in driving budgeting, funding, and partnerships. FF6 ($R_i - C_i$ = 0.3011, prominence 8.6957, rank 2) and FF10 ($R_i - C_i$= 0.2544, prominence 8.5182, rank 5) are also "cause" factors, reinforcing their influence on financial governance and resource mobilization. In contrast, FF1 ($R_i - C_i$= -0.1669, prominence 8.6793, rank 3), FF2 ($R_i - C_i$= -0.1191, prominence 8.6645, rank 4), FF9 ($R_i - C_i$= -0.2683, prominence 8.4527, rank 6), FF3 ($R_i - C_i$ = -0.0512, prominence 8.3388, rank 7), FF8 ($R_i - C_i$ = -0.2558, prominence 8.2762, rank 8), and FF4 ($R_i - C_i$ = -0.1403, prominence 8.0265, rank 9) are "effect" factors heavily reliant on the drivers to function effectively, underscoring the need for robust financial governance in Vietnam's HLM.

Table 18: The NS-DEMATEL Financial and Resources Factors Results

CSFs	R_i	C_i	$R_i + C_i$	$R_i - C_i$	Weight	Rank	Identify
FF1	4.2562	4.4231	8.6793	-0.1669	0.1135	3	Effect
FF2	4.2727	4.3918	8.6645	-0.1191	0.1133	4	Effect
FF3	4.1438	4.195	8.3388	-0.0512	0.109	7	Effect
FF4	3.9431	4.0834	8.0265	-0.1403	0.105	9	Effect
FF6	4.4984	4.1973	8.6957	0.3011	0.1137	2	Cause
FF7	4.6336	4.1875	8.8211	0.4461	0.1153	1	Cause
FF8	4.0102	4.266	8.2762	-0.2558	0.1082	8	Effect
FF9	4.0922	4.3605	8.4527	-0.2683	0.1105	6	Effect
FF10	4.3863	4.1319	8.5182	0.2544	0.1114	5	Cause

Figure 7, the Impact-Relation Heatmap, visually confirms these dynamics with influence scores from 0.4137 (weakest) to 0.5330 (strongest), excluding self-interactions. FF7 strongly influences FF6 (0.5330) and FF10 (0.5148), while FF6 impacts FF7 (0.5064) and FF9 (0.5164), and FF10 affects FF2 (0.4937) and FF6 (0.4703), shown in reddish-orange tones, affirming their proactive roles. FF1, FF2, and FF9 receive strong influences (e.g., FF7 → FF1 = 0.5279, FF6 → FF2 = 0.5156), while FF4 and FF8 exhibit weaker impacts (e.g., FF4 → FF8 = 0.4137, FF8 → FF4 = 0.4337), indicated by blue shades, reflecting their reactive nature. The analysis emphasizes that prioritizing FF7, FF6, and FF10 can enhance sustainability, transparency, and cost efficiency in resource mobilization, guiding policymakers to strengthen financial governance in Vietnam's HLM system.

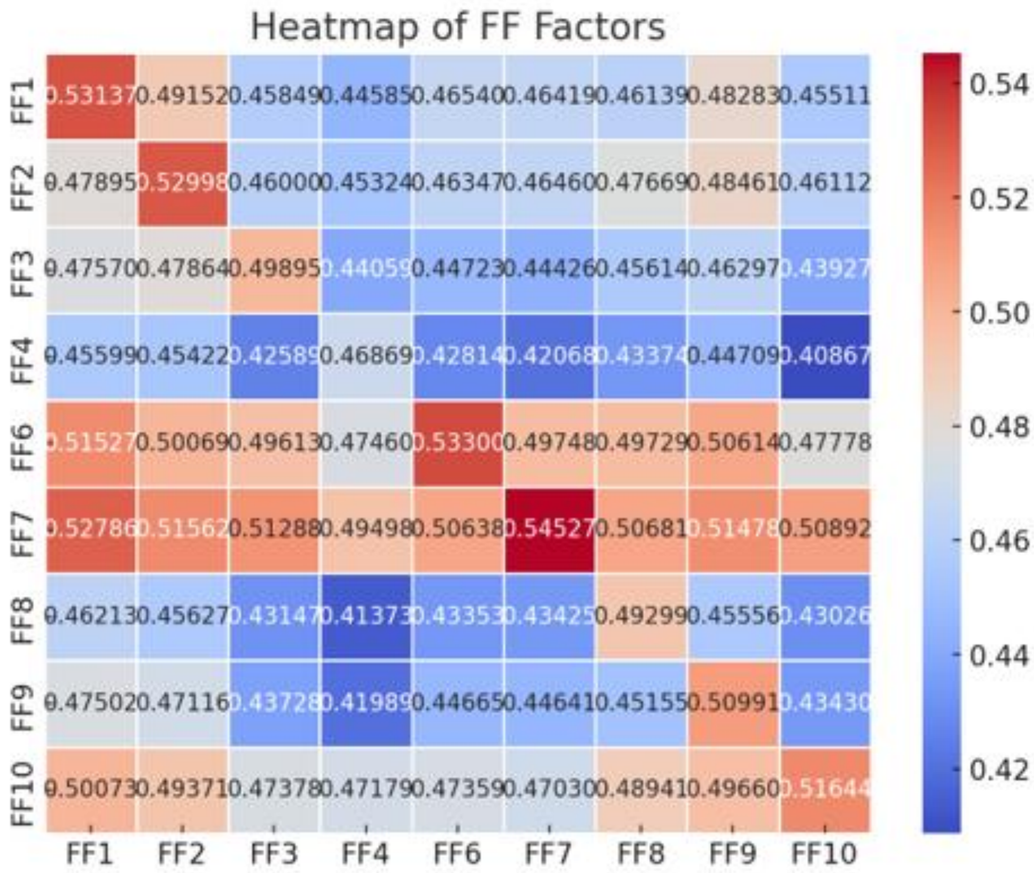

Figure 7: Impact-Relation heatmap of Financial and Resources Factors (FF)

4.3.6 NS-DEMATEL Social & Environmental Factors (EF) Results

The NS-DEMATEL analysis of Social and Environmental Factors in HLM in Vietnam, as presented in **Table 19** and **Figure 8**, interprets their roles and interdependencies (EF1 to EF10). **Table 19** identifies EF1 as the most prominent factor ($R_i + C_i$= 6.3092, weight 0.1316, rank 1) and a "cause" factor ($R_i - C_i$= 0.1386), highlighting the central role of community involvement in disaster recovery and response. EF10 ($R_i - C_i$ = 0.125, prominence 6.211, rank 2), EF4 ($R_i - C_i$= 0.4373, prominence 5.8013, rank 8), and EF6 ($R_i - C_i$ = 0.397, prominence 5.8334, rank 7) are also "cause" factors, supporting psychological foundations, knowledge, and safety for logistics operations. In contrast, EF2 ($R_i - C_i$= -0.4098, prominence 5.9744, rank 4), EF7 ($R_i - C_i$= -0.2876, prominence 6.046, rank 3), EF9 ($R_i - C_i$= -0.303, prominence 5.9026, rank 5), and EF5 ($R_i - C_i$= -0.0975, prominence 5.8815, rank 6) are "effect" factors, indicating their dependence on the broader system and suggesting that response effectiveness would be reduced without strategic investment in causal factors.

Table 19: The NS-DEMATEL Social and Environmental Factors

CSFs	R_i	C_i	$R_i + C_i$	$R_i - C_i$	Weight	Rank	Identify
EF1	3.2239	3.0853	6.3092	0.1386	0.1316	1	Cause
EF2	2.7823	3.1921	5.9744	-0.4098	0.1246	4	Effect
EF4	3.1193	2.682	5.8013	0.4373	0.121	8	Cause
EF5	2.892	2.9895	5.8815	-0.0975	0.1226	6	Effect
EF6	3.1152	2.7182	5.8334	0.397	0.1216	7	Cause

EF7	2.8792	3.1668	6.046	-0.2876	0.1261	3	Effect
EF9	2.7998	3.1028	5.9026	-0.303	0.1231	5	Effect
EF10	3.168	3.043	6.211	0.125	0.1295	2	Cause

Figure 8, the Impact-Relation Heatmap, with influence scores from 0.3003 (weakest) to 0.4461 (strongest), excluding self-interactions, further illustrates these dynamics. EF1 exerts strong influences on EF6 (0.4290) and EF7 (0.4283), while EF10 impacts EF9 (0.4461) and EF7 (0.4088), shown in reddish-orange tones, reinforcing their proactive roles. EF4 and EF6 also contribute notably (e.g., EF4 → EF1 = 0.4025, EF6 → EF7 = 0.4140), supporting system stability. Conversely, EF2, EF5, and EF9 receive moderate influences (e.g., EF1 → EF2 = 0.3456, EF10 → EF5 = 0.3949), while EF7 shows weaker impacts (e.g., EF7 → EF4 = 0.3049), indicated by blue shades, reflecting their reactive nature. The analysis underscores the need to prioritize proactive factors like EF1, EF10, EF4, and EF6 to create an effective HLM system, enhancing response and recovery capabilities in the face of increasingly complex natural disasters in Vietnam.

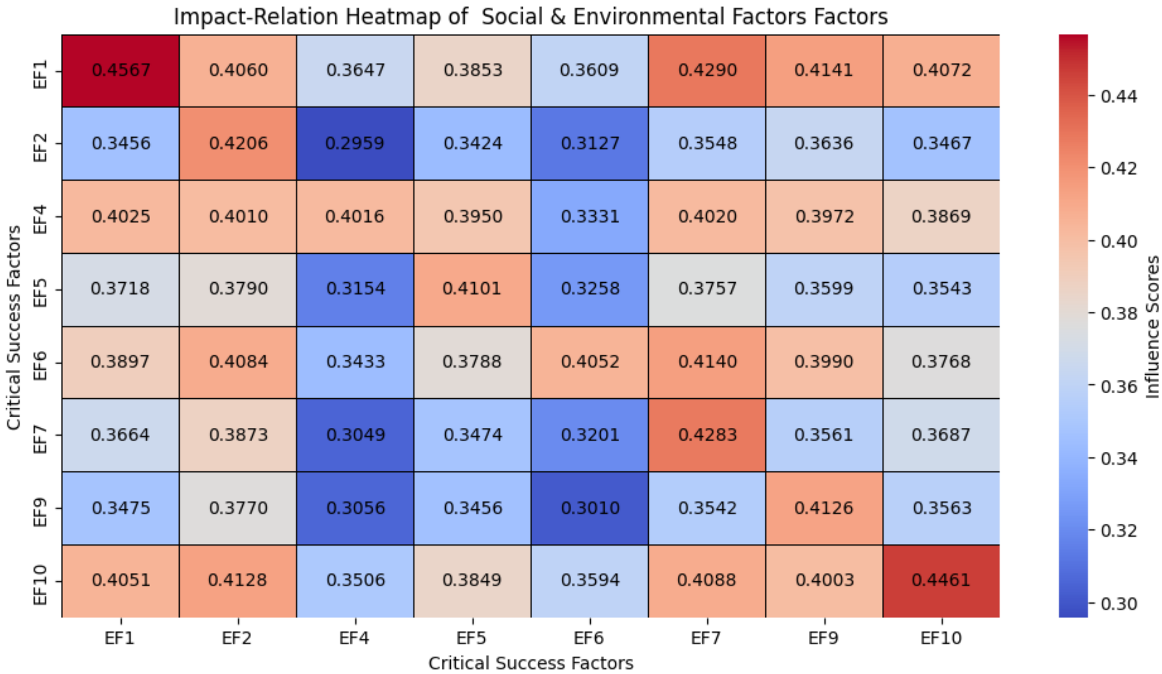

Figure 8: Impact-Relation Heatmap of Social and Environmental Factors

4.4 Results of CSFs' Weights

Weights were calculated using neutrosophic expert evaluations, aggregated into main criteria weights (M-w), sub-criteria weights (S-w), and final weights, ensuring a balanced representation of each CSF's importance. The results are presented in **Table 18**.

Table 18. CSFs' Weights

Main Criteria	M-w	Sub-criteria	S-w	Final weight
SF	0.209953523	SF1	0.11416591	0.02397
		SF2	0.111505	0.02341
		SF3	0.11791759	0.02476
		SF4	0.10838135	0.02276
		SF5	0.1097816	0.02305
		SF6	0.1135648	0.02384

		SF7	0.10870774	0.02282
		SF9	0.11033064	0.02316
		SF10	0.10564537	0.02218
OF	0.20016274	OF1	0.11398167	0.02281
		OF2	0.11046289	0.02211
		OF3	0.11460506	0.02294
		OF4	0.11418025	0.02285
		OF5	0.11310853	0.02264
		OF7	0.10318606	0.02065
		OF8	0.1100626	0.02203
		OF9	0.11052256	0.02212
		OF10	0.10989038	0.022
TF	0.20035289	TF1	0.12450198	0.02494
		TF3	0.12813344	0.02567
		TF4	0.12310337	0.02466
		TF5	0.12603707	0.02525
		TF6	0.12073249	0.02419
		TF7	0.12963173	0.02597
		TF9	0.12175537	0.02439
		TF10	0.12610455	0.02527
FF	0.20033963	FF1	0.11349397	0.02274
		FF2	0.11330175	0.0227
		FF3	0.10904074	0.02185
		FF4	0.10495888	0.02103
		FF6	0.11371104	0.02278
		FF7	0.11534784	0.02311
		FF8	0.1082245	0.02168
		FF9	0.11053199	0.02214
		FF10	0.11138929	0.02232
EF	0.18919122	EF1	0.13155318	0.02489
		EF2	0.12457368	0.02357
		EF4	0.12096228	0.02289
		EF5	0.1226341	0.0232
		EF6	0.12163316	0.02301
		EF7	0.1260642	0.02385
		EF9	0.1230792	0.02329
		EF10	0.1295002	0.0245

The NS-WASPAS weighting results highlight the balanced importance of strategic, technological, financial, and operational factors in Vietnam's HLM, with social and environmental considerations close behind. High-weight CSFs like TF7, TF3, and SF3 underscore the need for technological innovation and preparedness to enhance disaster response. Lower-weighted factors, such as OF7 and FF4, suggest areas for future development to strengthen human capacity and partnerships. These weights guide the NS-WASPAS ranking of strategies, ensuring alignment with Vietnam's HLM priorities.

4.4 NS-WASPAS Ranking and Sensitive Analysis

NS-WASPAS method ranked 15 strategies (S1–S15) for HLM in Vietnam, with sensitivity analysis conducted to evaluate ranking stability by varying the balancing parameter λ from 0 to 1. This approach mitigates potential biases in expert judgments, ensuring robust decision-making. **Table 19** presents the computed Qi scores for each strategy across λ values, reflecting their performance under different weighting scenarios.

The results emphasize prioritizing strategic planning, digitalization, and data analytics to strengthen Vietnam's HLM. Sensitivity analysis reinforces the model's consistency, providing policymakers with a reliable framework to develop and adapt strategies tailored to the dynamic challenges of disaster response in Vietnam.

Table 19. NS-WASPAS Rankings

CSFs	λ=0	λ=0.1	λ=0.2	λ=0.3	λ=0.4	λ=0.5	λ=0.6	λ=0.7	λ=0.8	λ=0.9	λ=1
S1	1.9974E-2	3.18461	6.36922	9.55383	12.73844	15.92305	19.10766	22.29227	25.47688	28.66149	31.8461
S2	1.8103E-2	3.18261	6.36522	9.54783	12.73044	15.91305	19.09566	22.27827	25.46088	28.64349	31.8261
S3	1.8595E-2	3.18311	6.36622	9.54933	12.73244	15.91555	19.09866	22.28177	25.46488	28.64799	31.8311
S4	2.0056E-2	3.18472	6.36944	9.55416	12.73888	15.9236	19.10832	22.29304	25.47776	28.66248	31.8472
S5	1.8805E-2	3.18349	6.36698	9.55047	12.73396	15.91745	19.10094	22.28443	25.46792	28.65141	31.8349
S6	1.842E-26	3.1829	6.3658	9.5487	12.7316	15.9145	19.0974	22.2803	25.4632	28.6461	31.829
S7	1.8649E-2	3.18322	6.36644	9.54966	12.73288	15.9161	19.09932	22.28254	25.46576	28.64898	31.8322
S8	1.8239E-2	3.18274	6.36548	9.54822	12.73096	15.9137	19.09644	22.27918	25.46192	28.64466	31.8274
S9	1.6557E-2	3.18068	6.36136	9.54204	12.72272	15.9034	19.08408	22.26476	25.44544	28.62612	31.8068
S10	1.8441E-2	3.18304	6.36608	9.54912	12.73216	15.9152	19.09824	22.28128	25.46432	28.64736	31.8304
S11	1.6985E-2	3.18115	6.3623	9.54345	12.7246	15.90575	19.0869	22.26805	25.4492	28.63035	31.8115
S12	1.9419E-2	3.18416	6.36832	9.55248	12.73664	15.9208	19.10496	22.28912	25.47328	28.65744	31.8416
S13	1.6971E-2	3.18117	6.36234	9.54351	12.72468	15.90585	19.08702	22.26819	25.44936	28.63053	31.8117
S14	1.7972E-2	3.18243	6.36486	9.54729	12.72972	15.91215	19.09458	22.27701	25.45944	28.64187	31.8243
S15	1.7875E-2	3.18227	6.36454	9.54681	12.72908	15.91135	19.09362	22.27589	25.45816	28.64043	31.8227

Sensitivity analysis revealed high stability in the ranking order, affirming the NS-WASPAS model's reliability under uncertainty, as shown in **Figure 9**. Strategies S1 (Strategic Planning and Policy Development), S4 (Digital Transformation in Humanitarian Logistics), and S12 (Data-Driven Disaster Response Management) consistently ranked highest across all λ values, underscoring their critical role in enhancing HLM efficiency. These strategies enable better coordination, real-time responsiveness, and data-driven decision-making, vital for addressing Vietnam's frequent and unpredictable natural disasters. In contrast, S9 (Green Humanitarian Logistics), S11 (Strengthening Governance and Legal Frameworks), and S13 (Donor Engagement and Sustainable Funding Models) consistently ranked lower, suggesting limited immediate impact or the need for foundational support before effective implementation. While relevant for long-term sustainability, these strategies are secondary to urgent priorities.

The results emphasize prioritizing strategic planning, digitalization, and data analytics to strengthen Vietnam's HLM. Sensitivity analysis reinforces the model's consistency, providing policymakers with a reliable framework to develop and adapt strategies tailored to the dynamic challenges of disaster response in Vietnam.

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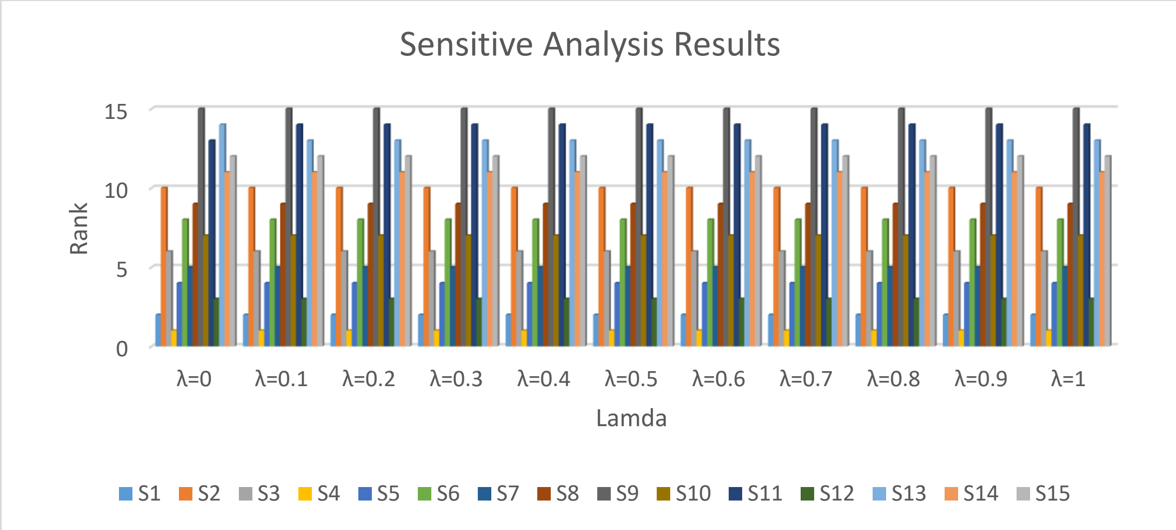

Figure 9: Sensitive Analysis Results

4.5 Comparative Analysis

To validate the robustness and consistency of the strategy rankings, a comparative analysis was conducted using three methods: NS-WASPAS (Version 1), NS-WASPAS (Version 2 with slightly perturbed expert inputs), and the conventional Simple Additive Weighting (SAW) technique. The results, illustrated in **Figure 10**, demonstrate strong alignment across the methods, reinforcing the reliability of the neutrosophic MCDM model.

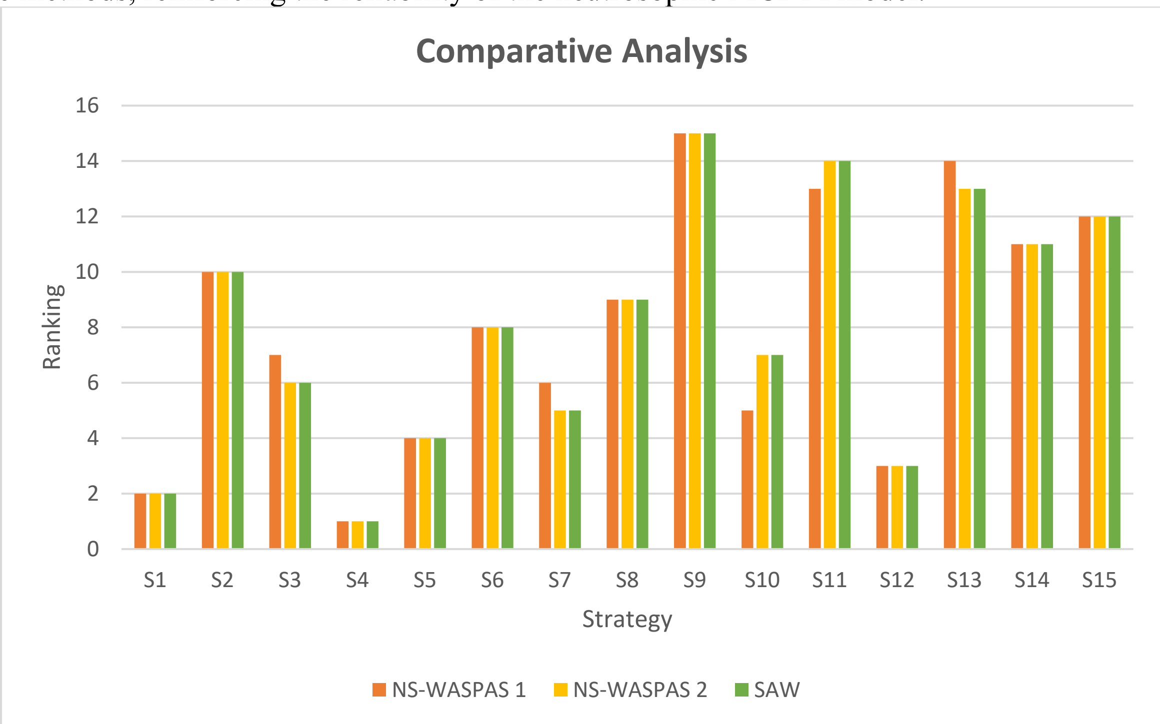

Figure 10: Comparative Analysis

The analysis revealed consistent prioritization across all methods, particularly for top-ranked strategies. S4 - Digital Transformation in Humanitarian Logistics secured the first rank in all approaches, reflecting unanimous expert consensus on its pivotal role in enhancing coordination, visibility, and responsiveness in HLM. Similarly, S1 - Strategic Planning and

Policy Development and S12 - Data-Driven Disaster Response Management consistently placed in the top three, underscoring their strategic importance for systemic preparedness and disaster readiness in Vietnam. Conversely, S9 - Green Humanitarian Logistics, S13 - Donor Engagement and Sustainable Funding Models, and S15 - Inclusive and Equitable Humanitarian Response ranked in the lower half across all methods, indicating their perceived role as long-term enablers rather than immediate priorities compared to system responsiveness and coordination.

Minor rank variations occurred among mid-tier strategies, such as S3 - Public-Private Partnerships and S7 - Capacity Building and Training, which fluctuated between ranks 5 and 7. These shifts suggest context-dependent expert judgments but remain within a narrow prioritization range. Notably, S10 - Multi-Modal Transport System Optimization showed the most variation, ranking 5th in NS-WASPAS (Version 1) but 7th in NS-WASPAS (Version 2) and SAW, likely due to sensitivity to weight assignments in neutrosophic versus crisp data environments. The minimal differences between NS-WASPAS versions highlight the model's internal stability, while its alignment with SAW—a widely trusted linear additive method—further validates the results.

In conclusion, the comparative analysis confirms the robustness of the NS-WASPAS model, which is resilient to data uncertainty and methodologically sound. The convergence across methods strengthens confidence in prioritizing S4, S1, S12, and S5 as critical levers for effectively enhancing Vietnam's HLM capacity to address future disasters.

4.6 Discussions

Research on humanitarian logistics management in the context of natural disasters in Vietnam has become an important topic, especially as the country faces increasing challenges from climate change and extreme weather events such as Typhoon Yagi in 2024. The results of this study have confirmed the effectiveness and suitability of applying the trio of integrated multi-criteria decision-making tools on the Neutrosophic Sets platform—including NS-Delphi, NS-DEMATEL, and NS-WASPAS—in identifying, analyzing, and ranking CSFs in HLM in a complex and uncertain context like Vietnam. Unlike traditional MCDM methods that rely on the assumption of certainty and clear quantitative data, the Neutrosophic Sets-based analytical framework allows for the independent modeling of three components: truth, indeterminacy, and falsity, thereby more realistically reflecting the ambiguous and inconsistent judgments often encountered in humanitarian decision-making [104]. The application of NS-DEMATEL helps clarify the cause-effect relationships between factors, in which factors such as Government Policy and Regulations (SF1), Real-Time Monitoring and Tracking (OF10), and Satellite and GIS for Route Optimization (TF10) emerge as core strategic levers that act as inputs to shape the effectiveness of the entire HLM system. This is consistent with international studies suggesting that governments guide policies and create a legal environment for effective inter-sectoral coordination, especially in emergencies [61], [105]. In addition, the ability to use real-time data through digital technologies such as GIS, IoT, and supply chain tracking systems is a decisive factor in the timeliness, transparency, and accuracy of relief distribution [103].

Particularly, the topicality and pragmatic application of the research are underlined in light of the 7.7-magnitude earthquake that struck the whole Southeast Asian region, from Myanmar to Thailand [106], severely damaging Myanmar, Bangkok, and many surrounding provinces [107]. Along with destroying several high-rise buildings and causing great casualties, this tragedy also disrupted important transit routes and closed off access to many isolated mountainous regions. Due to landslides, badly damaged bridges and culverts, and an almost complete lack of specialized transportation systems, the rescue crew had several challenges reaching the area in the initial hours following the earthquake—the golden moment. Many villages were isolated for many days, forcing rescue workers to travel by road and on foot or deploy rescue helicopters when conditions allowed—a costly and limited-scope option. More seriously, the lack of an up-to-date geographic data platform and real-time monitoring system has slowed decision-making, causing relief supplies to back up at some transit points while other areas remain severely underfunded [108]. The lack of a unified coordination mechanism between the government, the military, and NGOs has also led to overlapping or missing resource allocations. International humanitarian organizations, including the Red Cross, have acknowledged serious difficulties in determining priority locations and routes due to the lack of risk maps and accurate positioning tools. The recent devastating earthquake in Myanmar serves as a potent reminder of Southeast Asian countries' vulnerabilities when it comes to disaster response and readiness. They are not isolated events but reflect a more general, structural problem that bedevils the region and Vietnam. In Vietnam, issues of hard terrain, regimes of centralized administration, and low digital penetration continue to hamper the effectiveness and responsiveness of humanitarian logistics infrastructure. Myanmar's earthquake has also impacted Vietnam negatively since fault lines like the Red River, Son La, Lai Chau - Dien Bien, and the central coast region have been determined to be potentially active and result in cataclysmic earthquakes [109].

This geographical exposure points to a need for proactive, data-driven measures in building disaster response capacity. Accordingly, by extension, the NS-WASPAS findings also prioritize the top priority strategies such as Strategic Planning and Policy Development (S1), Digital Transformation in Humanitarian Logistics (S4), Enhancing Last-Mile Delivery Capabilities (S5), and Data-Driven Disaster Response Management (S12). These efforts not only identify the foremost issues of the experts with systems, technology, and sustainability but are also aligned with recommendations of international agencies such as IFRC (2020) [110] and ALNAP (2021) [111], which prioritize preparedness, strengthening local capacities, and enabling localized solutions in a bid to build disaster resilience. In particular, Data-Driven Disaster Response Management (S12) introduces a change in basic assumptions to data-driven, proactive coordination, enabling real-time visibility, predictive analytics, and fact-based decision-making in intricate emergency scenarios. This strategy is applied in the Philippines and Bangladesh, where the convergence of data, geospatial capabilities, and local response teams significantly enhanced the efficiency and fairness of disaster responses [112].

Furthermore, compared to countries with developed humanitarian logistics capabilities, such as Turkey and India, which have integrated geographic information systems and big data into regional logistics hubs, Vietnam still faces major challenges due to its centralized governance model and lack of investment in technology infrastructure to support real-time disaster management [113]. Therefore, applying the strategies proposed in this study is valuable in optimizing resource allocation and laying the foundation for building an adaptive, resilient, and technology-oriented disaster logistics ecosystem. Overall, the study not only makes an academic contribution in expanding the application of Neutrosophic logic in the humanitarian field, which is rich in uncertainty, but also has high practical significance, providing a set of reliable decision-making tools for policymakers, managers, and NGOs in designing and implementing humanitarian logistics strategies suitable for the specific socio-geographical conditions of Vietnam.

5 Conclusion, Implications, Limitations, and Future Work

5.1 Conclusions

This research presents a practical approach to determining, examining, and prioritizing the CSFs of humanitarian logistics management in Vietnam, a country heavily affected by natural disasters. With the integration of three methods, NS-Delphi, NS-DEMATEL, and NS-WASPAS, within the scope of the Neutrosophic Set, not only are uncertainty and ambiguity in expert data resolved, but cause-and-effect relationships are clearly defined among strategic, operational, technological, financial-resource, and social-environmental factors. The results show that factors such as disaster preparedness plans, digital transformation in logistics, and last-mile delivery capability significantly impact the performance of the entire humanitarian logistics system. At the same time, the study also points out priority strategies that need to be implemented to improve response capacity, including promoting digital transformation, building a community logistics network, enhancing multi-sectoral coordination, and ensuring equitable distribution of relief. The governance implications drawn from the study are not only of practical value for Vietnam but can also be extended to developing countries with similar characteristics in terms of geographical conditions and infrastructure. Finally, this study contributes to the academic foundation by applying and testing the effectiveness of Neutrosophic Sets in humanitarian logistics management while opening up new directions for future research in combining advanced quantitative methods to solve complex, uncertain problems in disaster management and humanitarian relief.

5.2 Theoretical Implications

This research makes several crucial theoretical contributions to humanitarian logistics and disaster management. First, it offers a synthesized and comprehensive method for dealing with uncertainty, expert prejudice, cause-and-effect relationships, and multi-criteria ordering. This framework synthesizes the theory backing decision-making models in adverse humanitarian conditions where information is generally incomplete, vague, or in a state of fast change. It widens the use field of MCDM instruments beyond industrial or corporate settings to societal and transportation issues in war-ravaged places like Vietnam. Second, the classification and analysis of 50 CSFs along strategic, operational, technological, financial, and environmental dimensions provide an extensive theoretical framework of how humanitarian logistics systems function under stress. This multi-faceted perspective enhances the literature by highlighting the intricate relationship between institutional management and operational and technological innovation. Moreover, the ordering of factors—such as Government Policy and Regulations (SF1), Real-Time Monitoring and Tracking (OF10), and Satellite and GIS for Route Optimization (TF10)—offers empirical grounding for theory development, supporting the notion that disaster response effectiveness relies not only on resources but also on systemic integration and alignment. Finally, the proposed strategies—such as Strategic Planning (S1), Digital Transformation (S4), Enhancing Last-Mile Delivery (S5), and Data-Driven Response (S12)—form a theoretical bridge between factor analysis and actionable frameworks. These strategies can be conceptual building blocks in future theoretical models aiming to design resilient, adaptive, and technology-driven humanitarian logistics systems. This study enhances theoretical discourse by offering methodological rigor and practical relevance, encouraging further academic inquiry into context-specific and scalable humanitarian logistics solutions.

5.3 Managerial Implications

The research results also have beneficial management implications for Vietnam's humanitarian logistics managers and policymakers. First and foremost, strategic plan formulation should be prioritized, and proactive response should be considered the pillar for all relief interventions, especially in the context of unparalleled natural disasters like the one currently experienced. Second, management agencies need to increase investment in digital transformation, applying technologies such as artificial intelligence, big data, and the Internet of Things to improve forecasting, monitoring, and distribution capacity more effectively. In addition, developing local logistics centers and mobilizing community participation will significantly improve last-mile delivery capabilities and ensure equitable and rapid access to affected areas. Strengthening coordination among government agencies, NGOs, and the private sector is also important to optimize resources and avoid duplication in relief activities. In addition, developing long-term, transparent, and effective funding mechanisms will help stabilize humanitarian budgets. Finally, integrating social and environmental factors, with a special focus on gender equality, environmental impact, and people's psychological support, will contribute to building a more inclusive and sustainable humanitarian logistics system in the long term.

5.4 Limitations and Future Works

Despite the novelty of integrating NSs and MCDM methods, this research has three main limitations that must be considered. First, the results of this study are mainly focused on the case of floods and storms in Vietnam, whereas generalizing the findings to other disaster types, such as earthquakes or droughts, needs further empirical studies to be tested. This requires expanding the scope of the study to ensure generalizability and applicability in different situations. For example, while floods and storms often involve evacuation and emergency relief distribution, earthquakes focus on rescue and infrastructure recovery, while droughts require long-term water resource management strategies and agricultural support. Therefore, testing the model's effectiveness in different disaster scenarios will enhance the reliability and applicability of the study. Second, static Neutrosophic models cannot reflect time-dynamic risks, i.e., the impact of climate-induced migration on relief demand forecasting—a limitation that has also been realized in research on crisis management in Bangladesh. Climate change not only increases the number and severity of natural disasters but also leads to migration and changes in settlement patterns of the population, which affect relief and recovery needs. Incorporation of stochastic models of disaster evolution would render predictions for complex climate change scenarios more flexible, allowing disaster managers to be more proactive regarding planning and resource allocation. Thirdly, the dominance of expert opinion (100% of panel members) over the perceptions of affected communities at the cost of local communities' opinions threatens the attainment of equity in humanitarian logistics. Community participation enhances equity in relief distribution and provides valuable local feedback on actual needs and accessibility in affected communities. This is especially important given that affected communities have in-depth knowledge of their terrain and social organization, which helps smooth the implementation of relief interventions.

To address these limitations, future studies should extend the NS framework by incorporating stochastic disaster evolution models, which provide more flexible forecasting for complex climate change scenarios. At the same time, conducting comparative cross-country research across ASEAN would also determine regional best practices, such as the Philippines' distributed logistics hub model or Indonesia's multi-layer early warning system. These can make Vietnam's relief and recovery operations more efficient. Finally, the combination of participatory GIS and Neutrosophic analysis will generate a real-time adaptive planning instrument that will allow for the introduction of local knowledge in resource allocation decisions. This tool has been successfully tested for flood risk management in Thailand. All these extensions expand the model's applicability and ensure the inclusiveness and sustainability of disaster management in Vietnam and the region.

Through the combination of GIS and Neutrosophic analysis, managers can create more responsive response plans tailored to local communities' needs and enhance the effectiveness of relief operations.

In conclusion, expanding the scope of research, adding disaster development modeling, and increasing communal involvement will make the Neutrosophic model more effective and applicable to disaster management. These approaches serve Vietnam and the development of ASEAN region disaster management, where experience and collaboration are crucial to counter the increasing challenges of climate change and natural disasters.

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