

Prioritizing Critical Success Factors in Humanitarian Supply Chains: A Hybrid Intuitionistic Fuzzy AHP-TOPSIS Approach

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ABSTRACT

An effective humanitarian supply chain is essential for a timely and equitable disaster response. However, prioritising critical success factors (CSFs) in such environments remains challenging due to uncertainty, dynamic stakeholder involvement, and constrained resources. This study proposes a hybrid decision-making framework that integrates the Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) and the Intuitionistic Fuzzy TOPSIS (IF-TOPSIS) to identify and prioritize CSFs in the humanitarian supply chain. The framework accommodates uncertainty and hesitation in expert assessments, offering a structured and adaptable method for complex decision-making. The analysis involved 12 experts from disaster response organisations in Indonesia. Eight main criteria and thirty-three sub-criteria were evaluated. The top-ranked CSFs include procurement and donation management (preference value: 0.778), empowerment of emergency teams (0.769), and social media & communication tools (0.766). These findings highlight the operational importance of agility, local decision-making, and real-time communication. The study contributes to humanitarian supply chains by offering a replicable method for CSF prioritisation under uncertain conditions. The proposed framework provides practical guidance for enhancing the performance of supply chains in disaster response and can support more effective decision-making in humanitarian operations.



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1. Introduction

The growing incidences of natural disasters, armed wars, pandemics, and other humanitarian emergencies place an enormous strain on the humanitarian supply chain (HSCs) worldwide [1]. Humanitarian supply chain management refers to the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of disaster relief goods and materials [2]. It also involves managing related information from the point of origin to the point of consumption, thereby alleviating the suffering of vulnerable populations. Compared to commercial supply chains, humanitarian supply



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chain management operates under significant uncertainty, including volatile demand, unknown environments, damaged infrastructure, and limited decision-making time. Humanitarian supply chain management has a substantial impact on disaster response [3]. Its effectiveness directly impacts the survival rate and welfare of affected communities in the initial aftermath. Understanding and managing the factors that determine success are referred to as Critical Success Factors (CSFs). The CSFs involve a broad spectrum of strategic, operational, technological, and organizational elements that collectively impact the performance of humanitarian supply chains [4]. However, due to the dynamic and complicated nature of humanitarian operations, determining which CSFs should be prioritized necessitates a planned and systematic methodology. When determining the relative relevance of various aspects, decision-makers frequently encounter ambiguous, inconsistent, or incomplete data. Furthermore, the perspectives of numerous stakeholders (government agencies, non-governmental organizations, logistical providers, and affected communities) add levels of complexity that must be addressed. The requirement for modern decision-support technologies that can deal with imprecision while also capturing expert judgments in a comprehensive and flexible manner.

To address these challenges, the adoption of the Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) and Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (IF-TOPSIS) has garnered attention in recent years. The IF-AHP and TOPSIS are well-regarded for their ability to accommodate uncertainty, hesitation, and imprecision in expert assessments. The IF-AHP provides an organised approach to evaluate the relative relevance of various criteria through the combination of degrees of membership, non-membership, and hesitancy in expert assessments [5]. IF-TOPSIS enhances the approach through permitting alternatives to be prioritised based on their distance from an ideal solution [6]. Additionally, IF-TOPSIS enables robust prioritisation even in unclear or conflicting situations. Previous studies have demonstrated the effectiveness of the integrated IF-AHP and IF-TOPSIS in various fields, including ranking production strategies [6], determining the safest route [7], and selecting products for development [7, 8]. Such analytical frameworks are especially useful in situations where limited resources and time constraints necessitate prompt yet accurate decisions. Combining IF-AHP and IF-TOPSIS can systematically identify and rank critical success factors (CSFs), leading to improved preparedness, coordination, and response.

Despite advancements in decision-making methodologies across various domains, substantial research gaps persist in humanitarian supply chains. Many existing studies still rely on traditional decision-making approaches that assume the availability of precise, consistent, and complete data. Conventional methods are frequently insufficient in the face of high uncertainty, rapidly changing environments, and fragmented information. Moreover, although Intuitionistic Fuzzy AHP and Intuitionistic Fuzzy TOPSIS have been widely applied, their use in the humanitarian supply chain remains limited. These studies fail to reflect the distinct characteristics of humanitarian supply chains, such as the urgency of reaction, the multiplicity of stakeholders, and the unpredictability of field conditions. Additionally, much of the prior literature has treated CSFs as independent variables, without acknowledging the interactions and trade-offs that often exist between them. Elements such as procurement efficiency, coordination among emergency teams, communication infrastructure, and stakeholder collaboration are frequently interconnected. Ignoring these interdependencies may lead to suboptimal prioritisation and reduce the effectiveness of response strategies. Therefore, there is a clear need for a more holistic, adaptable, and uncertainty-resilient framework that can

guide decision-makers in prioritizing CSFs under the constraints of humanitarian settings.

2. Methods

This study began with the distribution of structured questionnaires to nine experts selected purposively. The experts consisted of representatives from the Regional Disaster Management Agency (BPBD) in Indonesia, humanitarian volunteers, academics with expertise in disaster logistics, and logistics business practitioners who were directly involved in disaster response operations. Respondents were selected based on their substantial experience in planning, implementing, and evaluating humanitarian supply chains. The assessments provided by the experts served as the basis for developing a paired comparison matrix during the criteria analysis stage. The methodological approach in this study is described in two main stages, as shown in Figure 1. The first stage uses the IF-AHP method to determine the relative importance weight of each criterion. The second stage applies the IF-TOPSIS method to rank the identified critical success factors (CSFs). This framework is designed to address uncertainty and doubt in expert assessments, providing a systematic, flexible, and data-driven approach to decision-making.

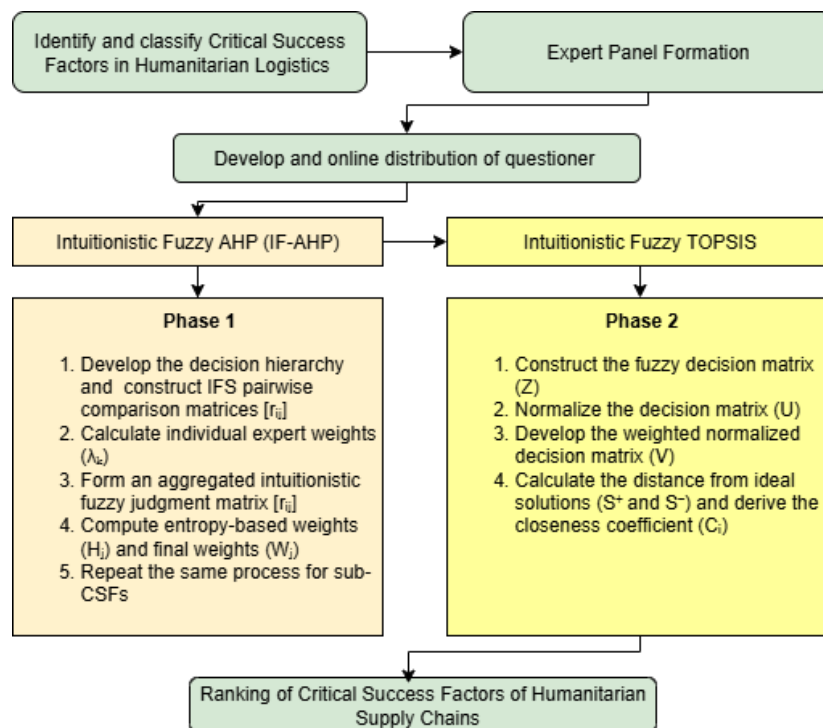


Figure 1. Research stages

2.1 Intuitionistic Fuzzy Set

The Intuitionistic Fuzzy Set (IFS) theory was introduced by Atanassov in 1986 as an extension of classical fuzzy set theory. Atanassov argued that although the conventional definition of fuzzy is theoretically valid, its application in real-world situations is often inadequate due to incomplete information in comprehensively



representing a concept [9]. To overcome these limitations, IFS introduces additional dimensions, including membership degree, non-membership degree, and hesitation degree.

In the IFS framework, each element in the set has an explicit value for these three parameters. Suppose X is the universal set and $A \subseteq X$. Then, the intuitionistic fuzzy set \tilde{A} is defined in Equation (1).

$$\tilde{A} = \{ \langle x, \mu_A(x), \nu_A(x) \rangle \mid x \in X \} \tag{1}$$

In the formulation (1), $\mu_A(x)$ represents the degree of membership of element $x \in X$ and belongs to the set A , while $\nu_A(x)$ represents the degree of non-membership. For every $x \in X$, it holds in formulation in Equation (2). The difference between total membership and non-membership with complete units represents the degree of doubt or uncertainty regarding the status of element x in set A , which is referred to as the degree of hesitation $\pi_A(x)$, as formulated in Equation (3).

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1 \tag{2}$$

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x) \tag{3}$$

This approach is more flexible in dealing with uncertainty and ambiguity, especially in the context of expert assessments that are not always deterministic or complete.

2.2 Intuitionistic Fuzzy AHP (IF-AHP)

The IF-AHP method is used to systematically determine the relative importance weights of each criterion in multi-criteria decision making involving uncertainty. This approach combines membership degrees (μ), non-membership degrees (ν), and uncertainty degrees (π) to capture expert perceptions more comprehensively [10]. The implementation process of the IF-AHP method is carried out through the following steps:

Step 1: Construction of the decision hierarchy, criteria, and alternatives.

The hierarchical structure consists of three levels, starting with the primary objective at the first level, followed by the main critical success factors (CSFs) at the second level, and related sub-factors at the third level. This hierarchy enables a structured approach to evaluating the relationships between elements.

Step 2: Determining each decision maker's weights (λ_k)

The relative influence of each decision maker is determined based on linguistic assessments converted into intuitionistic fuzzy numbers (IFNs). Linguistic values and their conversion to IFNs are presented in Table 1 [11]. The expert weight (λ_k) is calculated using Equation (4).

$$\lambda_k = \frac{\left(\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \vartheta_k} \right) \right)}{\sum_{k=1}^K \left(\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \vartheta_k} \right) \right)} \text{ where } \sum_{k=1}^K \lambda_k = 1 \tag{4}$$

Let K denote the total number of decision makers, and $\lambda = (\lambda_1, \lambda_2, \lambda_3, \dots, \lambda_K)$ represent the weight vector assigned to each decision maker. Each weight λ_k is a non-negative real number and greater than zero.

Table 1. Linguistic terms and IF values

Linguistic Variables	IF Values (μ, ϑ, π)
Very Important (VI)	(0.9;0.10;0.00)
Important (I)	(0.75;0.20;0.05)
Medium Importance (MI)	(0.5;0.45;0.05)
Unimportant (U)	(0.35;0.60;0.05)
Very Unimportant (VU)	(0.10;0.90;0.00)

Step 3: Aggregation of IF Judgments

After determining the weight of each decision maker, the next step is to form an aggregate fuzzy intuitionistic assessment matrix using the Intuitionistic Fuzzy Weighted Averaging (IFWA) method. This matrix combines the assessments of all experts for each pair of criteria based on their relative weights. An aggregated intuitionistic fuzzy assessment matrix ($IFWA_\lambda$) is constructed by combining the evaluations from all experts using their respective weights. The final assessment for the R_{ij} element is calculated using the IFWA formula shown in Equation (5).

In this formula, $\mu_{ij}^{(k)}$ represents the degree of membership of the k -th expert's assessment for criterion i against j . $\vartheta_{ij}^{(k)}$ represents the degree of non-membership, λ_k is the weight of the k -th expert, and π_{ij} is the degree of uncertainty calculated as the difference between two exponential multiplication results on the third element.

This formula accommodates variations in assessment between experts by assigning weights to each of their contributions based on their level of expertise. The final result of the aggregation is compiled in the form of an intuitive fuzzy R pairwise comparison matrix.

$$R_{ij} = IFWA_\lambda (r_{ij}^{(1)}, r_{ij}^{(2)}, \dots, r_{ij}^{(t)}) = A_1 r_{ij}^{(1)} \oplus A_2 r_{ij}^{(2)} \oplus \dots \oplus A_t r_{ij}^{(t)}$$

$$R_{ij} = \left(\begin{array}{c} 1 - \prod_{k=1}^K (1 - \mu_{ij}^{(k)})^{\lambda_k}, \\ \prod_{k=1}^K ((\vartheta_{ij}^{(k)})^{\lambda_k}), \\ \prod_{k=1}^K (1 - \mu_{ij}^{(k)})^{\lambda_k} - \prod_{k=1}^K ((\vartheta_{ij}^{(k)})^{\lambda_k}) \end{array} \right) \tag{5}$$

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n1} & \dots & r_{nn} \end{bmatrix}$$

A paired comparison matrix R is then formed using Intuitionistic Fuzzy Numbers (IFNs) as shown in Table 2 [11], incorporating all criteria comparisons. R_{ij} represents the intuitionistic fuzzy rating given by the k -th decision maker for alternative i under criterion j . The term $(\mu_{ij}^{(k)})^{\lambda_k}$ indicates the weighted membership degree, reflecting how well alternative i satisfies criterion j based on the k -th decision maker's judgment.



Table 2. Linguistic variables for pairwise comparison

Linguistic Variable	IF Values	Reciprocal
Equally Important (EI)	(0.02;0.18;0.80)	(0.18;0.02;0.80)
Intermediate (IV)	(0.06;0.23;0.70)	(0.23;0.06;0.70)
Moderately More Important (MI)	(0.13;0.27;0.60)	(0.27;0.13;0.60)
Intermediate (IV2)	(0.22;0.28;0.50)	(0.28;0.22;0.50)
Strongly More Important (SI)	(0.33;0.27;0.40)	(0.27;0.33;0.40)
Intermediate (IV3)	(0.47;0.23;0.30)	(0.23;0.47;0.30)
Very Strong Importance (VSI)	(0.62;0.18;0.20)	(0.18;0.62;0.20)
Intermediate (IV4)	(0.80;0.10;0.10)	(0.10;0.80;0.10)
Extremely More Important (EMI)	(1.00;0.00;0.00)	(0.00;1.00;0.00)

Step 4: Consistency Check

To ensure the validity and logical consistency of expert assessments in the paired comparison matrix, a consistency ratio (CR) calculation is performed. This ratio is used to identify significant inconsistencies in the subjective assessments of decision-makers. The CR value is calculated based on the Random Index (RI) and the hesitation value $\pi_{ij}(x)$ using the formula in Equation (6).

In Equation (6), n indicates the number of elements in the comparison matrix, and $\pi_{ij}(x)$ is the hesitation degree value between elements *i* and *j*. A CR value that is less than or equal to 0.10 is considered to be within acceptable limits. If the value exceeds 0.10, the comparison matrix must be reviewed and corrected. The Random Index (RI) values used in CR calculations based on matrix size are presented in Table 3.

$$CR = \frac{RI - \sum \pi_{ij}(x)/n}{n - 1} \tag{6}$$

Table 3. Random Index (RI) values based on matrix size

Matrix Size (N)	1-2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54	1.56	1.57	1.59

Step 5: Ranking the criteria and alternatives

After the initial weights of the criteria were obtained using the IF-AHP method, further adjustments were made using intuitionistic fuzzy entropy theory to improve the objectivity of the weights. This method assesses the degree to which the information provided by each criterion is uncertain or ambiguous. It assigns weights based on the level of information discrimination. The entropy weight for each criterion W_i is calculated using the intuitionistic fuzzy entropy formula in Equation (7).

In Equation (7), μ_j , ν_j , and π_j represent the membership, non-membership, and uncertainty degrees of the *k*th criterion, respectively; while n is the total number of criteria evaluated. This formula adjusts the weight based on the wealth of information provided by the criterion—the lower the entropy, the higher the level of information clarity, and therefore the weight will increase.

$$\bar{w}_i = -\frac{1}{n \ln 2} [\mu_j \ln \mu_j + \nu_j \ln \nu_j - (1 - \pi_j) \ln (1 - \pi_j) - \pi_j \ln 2] \tag{7}$$

Table 4. The critical success factor of the humanitarian supply chain

Main Criteria	Sub-Criteria	Brief Description	Reference
1. Management and Leadership (ML)	Planning and organizing (ML1)	Systematic planning and organizing of relief operations	[12, 13]
	Strategic planning for emergency relief (ML2)	Short- and long-term plans to manage emergency relief	[12, 13]
	Top management support (ML3)	Involvement and support from top-level leadership	[13, 14]
	Change management (ML4)	Organizational ability to adapt during crises	[12]
	Growth and continuous improvement (ML7)	Ongoing efforts to enhance preparedness and response	[12, 14]
	Procurement and donation management (ML8)	Efficient handling of procurement and donation flows	[4, 12-14]
2. Coordination and Stakeholder Involvement (CS)	Inter-agency coordination (CS1)	Coordination among multiple agencies involved in relief	[13]
	Stakeholder cooperation and coordination (CS2)	Active involvement of NGOs, government, hospitals, etc.	[4, 12-15]
	Supplier and customer relationship management (CS3)	Managing relationships with aid suppliers and beneficiaries	[4, 12-14]
	Cross-functional teams (CS4)	Collaborative teams involving different functional units	[4, 12-14]
3. Education, Training, and Capacity Building (ET)	Staff training and education (ET1)	Training and educating personnel in humanitarian response	[13, 16]
	Technical skills and knowledge retention (ET2)	Maintaining essential technical skills and institutional memory	[13, 16]
	Need-based stakeholder training (ET3)	Training tailored to specific stakeholder needs	[14, 17]
	Empowerment of emergency teams (ET4)	Strengthening the autonomy and capacity of response teams	[16]
4. Technology and Information Systems (TI)	ICT and information systems (TI1)	Use of modern information and communication technologies	[12, 16]
	System integration and architecture (TI2)	Integration and design of digital systems and platforms	[13, 16, 18]
	Social media & communication tools (TI3)	Use of social media and tools for emergency communication	[13, 19]
5. Assessment and Forecasting (AF)	Rapid needs assessment (AF1)	Quick evaluation of the needs of disaster victims	[12, 16]
	Pre-warning and early warning systems (AF2)	Systems to provide disaster alerts and early warnings	[15]
	Forecasting accuracy (AF3)	Precision in forecasting needs and supply chain demands	[16, 20]
6. Resource and Financial Management (RF)	Availability of relief materials and equipment (RF1)	Availability of emergency supplies and equipment	[16, 21]
	Financial planning and transparency (RF2)	Proper financial planning and budget transparency	[16, 22]
	Effective use of limited resources (RF3)	Efficient utilization of scarce resources	[4, 12-14]
	Inventory management (RF4)	Managing stock levels and logistics of relief items	[12, 16]
	Economic conditions (RF5)	Economic environment affecting aid delivery operations	[15]
	Cost efficiency (RF6)	Minimizing costs in procurement and distribution	[23]
7. Infrastructure and Transportation (IT)	Road and transport network (IT1)	Availability and quality of transport infrastructure	[16, 21, 24]
	Fleet and logistics coordination (IT2)	Coordination of vehicles and logistic activities	[16]
	Accessibility of hospitals and clinics (IT3)	Ease of access to medical facilities for victims	[16, 25]
	Quick restoration of connectivity (IT4)	Rapid reestablishment of physical and digital links post-disaster	[16]
8. Socio-Cultural and Political Context (SC)	Socio-cultural factors (SC1)	Local norms, values, and perceptions influencing aid reception	[4]
	Political context (SC2)	Political stability and governmental support mechanisms	[4]
	Religion of beneficiaries (SC3)	Religious considerations in distributing aid fairly	[4]

2.3 Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

After the weights of each criterion and sub-criterion of critical success factors (CSFs) are obtained through the IF-AHP method, the next step is to rank the available alternatives using the Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (IF-TOPSIS) method. This method is used to evaluate the extent to which the performance of each alternative approaches the ideal solution based on predetermined criteria.

Step 1: Construct the Decision Matrix

An intuitive fuzzy decision matrix is formed to evaluate each alternative against each of the CSFs. Each element of this matrix is represented as a triplet $R_{ij} = (\mu_{ij}, \nu_{ij}, \pi_{ij})$, which describes the degree of membership, non-membership, and uncertainty for the i -th alternative on the k -th criterion. The aggregate value is calculated using expert weights according to the formula in Equation (8). The result of this step is an $m \times n$ fuzzy intuitionistic decision matrix R , where m is the number of alternatives and n is the number of criteria.

$$r_{ij} = \left[1 - \prod_{k=1}^K \left(1 - \mu_{ij}^{(k)} \right)^{\lambda k}, \prod_{k=1}^K \left(\nu_{ij}^{(k)} \right)^{\lambda k}, \prod_{k=1}^K \left(1 - \mu_{ij}^{(k)} \right)^{\lambda k} - \prod_{k=1}^K \left(\nu_{ij}^{(k)} \right)^{\lambda k} \right] \quad (8)$$

$$R = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1q} \\ x_{21} & x_{22} & \dots & x_{2q} \\ \vdots & \vdots & & \vdots \\ x_{p1} & x_{p2} & \dots & x_{pq} \end{bmatrix}$$

Step 2: Normalize the Decision Matrix and weighted IF-TOPSIS

Setelah matriks keputusan fuzzy terbentuk, setiap elemen matriks dinormalisasi menggunakan metode normalisasi vektor. Nilai hasil normalisasi dinyatakan dalam bentuk $r'_{ij} = (\mu'_{ij}, \nu'_{ij}, \pi'_{ij})$, dengan rumus pada Persamaan (9).

$$U = R \otimes W = (\mu'_{ij}, \nu'_{ij}) \quad (9)$$

$$= \{(x, \mu_{ij} \cdot \mu_j, \nu_{ij} + \nu_j - \nu_{ij} \cdot \nu_j), x \in X\} \pi_{ij} = 1 - \nu_{ij} - \nu_j - \mu_{ij} \cdot \mu_j + \nu_{ij} \cdot \nu_j$$

Let $r'_{ij} = (\mu'_{ij}, \nu'_{ij}, \pi'_{ij})$, where $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$, represent the elements of the aggregated (normalized) decision matrix R' . The result of this process is a normalized fuzzy decision matrix R , which forms the basis for the weight calculation step.

Step 3: Calculate Weighted Normalized Matrix

The normalized values of each element u_{ij} are then multiplied by the respective weights w_j of each criterion, which have been obtained from the IF-AHP method. This process produces a weighted normalized matrix V , with Equation (10).

$$v_{ij} = w_j \cdot u_{ij} \quad (10)$$

Matrix V is the final representation of alternative performance against CSF based on criteria weights.

Step 4: Calculate Distances and Ranking

The next step is to calculate the distance of each alternative from the positive ideal solution (D_i^+) and the negative ideal solution (D_i^-). The distance is calculated using the Euclidean formula in Equations (11) and (12). A positive ideal solution represents the best value of all alternatives for each criterion. In contrast, a negative ideal solution reflects the worst value.

$$D_i^+ = \sqrt{\sum_{j=1}^q (v_{ij} - v_j^+)^2} \quad (11)$$

$$D_i^- = \sqrt{\sum_{j=1}^q (v_{ij} - v_j^-)^2} \quad (12)$$

Finally, the proximity coefficient CC_i^+ is calculated for each alternative, indicating how close the alternative is to the ideal solution. This value is calculated using the formula in Equation (13).

$$CC_i^+ = \frac{D_i^-}{D_i^+ + D_i^-} \quad (13)$$

Alternatives are ranked based on their CC_i^+ values, where higher values indicate closer proximity to the ideal solution.

3. Results and Discussion

The identification of CSFs and related sub-factors was conducted through a literature review and supplemented with insights from an expert panel. The experts consisted of nine Indonesian disaster management professionals (BPBD), five humanitarian volunteers, two academics, and one logistics practitioner. Furthermore, the experts were engaged through structured questionnaires to ensure the relevance and contextual alignment of the selected factors. We found the experts using a purposive sample augmented through snowball recruitment. Moreover, the main criteria and sub-criteria for the critical success factors of the humanitarian supply chain are presented in Table 4.

3.1 Results from IF-AHP Analysis

The Intuitionistic Fuzzy AHP (IF-AHP) analysis reveals the prioritisation of critical success factors (CSFs) in humanitarian supply chains based on expert judgements. The significance of each decision maker was assessed using linguistic variables, as outlined in Table 1. To ensure a representative evaluation, five expert groups involved in disaster supply chains in West Sumatra, Indonesia, were consulted, including Indonesian disaster management professionals (BPBD), humanitarian volunteers, academics, and logistics practitioners. The importance levels were determined based on expert judgments and author evaluations. The corresponding decision-making weights were calculated using Equation (4) and are presented in Table 5.



Table 5. The weight of each expert group

Decision Maker Group (GDM)	Weighted	Linguistic Terms	Expert weight (λ)
GDM1	Very Important (VI)	(0.9;0.10;0.00)	0.299
GDM2	Important (I)	(0.75;0.20;0.05)	0.263
GDM3	Important (I)	(0.75;0.20;0.05)	0.263
GDM4	Medium Importance (MI)	(0.5;0.45;0.05)	0.175

To determine the weights of the criteria, pairwise comparison questionnaires were distributed to the expert group. Furthermore, create a comparison matrix for both main and sub-criteria (see the example in Table 6) where the importance weights were calculated using Equations (5-8). The final weights are summarised in Table 7. Additionally, all consistency ratios (CR) values were found to be below the threshold of 0.10, confirming the reliability of the expert judgments.

Table 6. Main criteria decision matrix

	ML	CS	ET	SC
ML	(0.02;0.18;0.80)	(0.02;0.18;0.80)	(0.13;0.27;0.60)		(0.13;0.27;0.60)
CS	(0.02;0.18;0.80)	(0.02;0.18;0.80)	(0.13;0.27;0.60)		(0.06;0.23;0.70)
ET	(0.80;0.10;0.10)	(0.47;0.23;0.30)	(0.80;0.10;0.10)		(0.47;0.23;0.30)
⋮					
SC	(0.80;0.10;0.10)	(0.62;0.18;0.20)	(0.62;0.18;0.20)		(0.13;0.27;0.60)
CR	0.011	0.023	0.028		0.015

The weight of CSFs is presented in three levels: the weight of each main criterion (W_m), the weight of sub-criteria within each main factor (W_s), and the global weight (W_G). The prioritisation results presented in Table 7 provide valuable insights into the relative importance of CSFs in humanitarian supply chain management. Among the eight main criteria, Technology and Information Systems (TI) and Coordination and Stakeholder Involvement (CS) were the most impactful factors, with sub-components receiving significant global weights. Specifically, the sub-criteria ICT and Information Systems (TI1), System Integration and Architecture (TI2), and social media and Communication Tools (TI3) all earned high global weights (0.051-0.0553). The current situation highlights an increasing reliance on digital infrastructure to facilitate rapid and coordinated humanitarian operations. It aligns with previous investigations that emphasise the importance of integrated information systems in enhancing visibility, speed, and responsiveness in disaster relief efforts [26].

Supplier and Customer Relationship Management (CS3) received the highest score among CS-related sub-criteria (0.043), underlining the importance of external relationships and stakeholder trust-building. According to the literature, inter-organisational collaboration, particularly with suppliers and local actors, considerably enhances last-mile delivery and supply chain agility during emergencies [27, 28]. Furthermore, Infrastructure and Transportation (IT) was a primary criterion, displaying substantial influence, with Road and Transport Network (IT1) receiving a global weight of 0.043. This finding is consistent with frequently encountered operational challenges where inadequate infrastructure often hinders access to affected populations [29]. Interestingly, both Management and Leadership (ML) and Resource and Financial Management (RF) were regarded as structurally significant. Their impact appears to be more scattered and less dominant than the technology and coordination dimensions. This

distribution implies that although financing and leadership are crucial, they are not perceived as instant facilitators during the execution stage of relief logistics. Subramony, et al. [30] reported similar results, arguing that leadership support enhances the efficacy of other operational responsibilities. Subsequently, Socio-Cultural and Political Context (SC) had a non-negligible impact, particularly through the sub-criterion Socio-cultural Factors (SC1), which had a reasonably high global weight of 0.039%. It underscores the importance of culturally informed interventions that respect local values and customs, as underlined by Adem, et al. [31].

Table 7. The weight of CSFs criteria and sub-criteria

Main Criteria	Main Weight (W_m)	Sub-Criteria	Sub-Criteria Weight (W_s)	Global Weight ($W_G = W_m \times W_s$)		
1. Management and Leadership (ML)	0.151	Planning and organising (ML1)	0.192	0.029		
		Strategic planning for emergency relief (ML2)	0.174	0.026		
		Top management support (ML3)	0.162	0.024		
		Change management (ML4)	0.151	0.023		
		Growth and continuous improvement (ML7)	0.16	0.024		
		Procurement and donation management (ML8)	0.161	0.024		
		2. Coordination and Stakeholder Involvement (CS)	0.157	Inter-agency coordination (CS1)	0.243	0.038
				Stakeholder cooperation and coordination (CS2)	0.257	0.040
Supplier and customer relationship management (CS3)	0.276			0.043		
Cross-functional teams (CS4)	0.224			0.035		
3. Education, Training, and Capacity Building (ET)	0.104			Staff training and education (ET1)	0.21	0.022
		Technical skills and knowledge retention (ET2)	0.261	0.027		
		Need-based stakeholder training (ET3)	0.245	0.025		
		Empowerment of emergency teams (ET4)	0.284	0.030		
4. Technology and Information Systems (TI)	0.155	ICT and information systems (TI1)	0.344	0.053		
		System integration and architecture (TI2)	0.328	0.051		
		Social media & communication tools (TI3)	0.328	0.051		
5. Assessment and Forecasting (AF)	0.082	Rapid needs assessment (AF1)	0.368	0.030		
		Pre-warning and early warning systems (AF2)	0.322	0.026		
		Forecasting accuracy (AF3)	0.31	0.025		
6. Resource and Financial Management (RF)	0.109	Availability of relief materials and equipment (RF1)	0.193	0.021		
		Financial planning and transparency (RF2)	0.179	0.020		
		Effective use of limited resources (RF3)	0.167	0.018		
		Inventory management (RF4)	0.148	0.016		
		Economic conditions (RF5)	0.178	0.019		
		Cost efficiency (RF6)	0.126	0.014		
7. Infrastructure and Transportation (IT)	0.144	Road and transport network (IT1)	0.298	0.043		
		Fleet and logistics coordination (IT2)	0.272	0.039		
		Accessibility of hospitals and clinics (IT3)	0.23	0.033		
		Quick restoration of connectivity (IT4)	0.2	0.018		
8. Socio-Cultural and Political Context (SC)	0.098	Socio-cultural factors (SC1)	0.401	0.039		
		Political context (SC2)	0.328	0.032		
		Religion of beneficiaries (SC3)	0.271	0.027		

3.2 Final Ranking using IF-TOPSIS

Following the calculation of criteria weights using the IF-AHP method, the IF-TOPSIS approach was applied to evaluate and rank the CSFs. The detailed results of this analysis are presented in Table 8. The ranking of the sub-criteria under the Critical Success Factors (CSFs) was determined using Equations (8-13). An intuitionistic fuzzy decision matrix was first constructed using IF values in Table 1. Furthermore, the matrix was then normalised, and the weights from the IF-AHP were applied to create a weighted, normalised matrix. Moreover, the positive ideal solution (D^+) and negative ideal solution (D^-) were identified using Equations (11) and (12). Each alternative from both the ideal solutions was calculated to determine its closeness coefficient.

The results of the IF-TOPSIS analysis show the final ranking of 33 critical sub-factors in humanitarian supply chains, as shown in Figure 2. The highest priority was given to procurement and donation management (ML8), with a preference value of 0.778. The prominence of this factor underscores its centrality in humanitarian supply chains, where the timely and efficient acquisition and allocation of goods are fundamental to the success of relief efforts. Effective procurement ensures not only the availability of essential supplies but also enhances operational transparency and donor confidence. As emphasized by Thakur-Weigold, et al. [32], robust procurement and donation management practices play a pivotal role in minimizing resource wastage, expediting delivery cycles, and aligning the distribution of aid with real-time needs on the ground. Their findings corroborate the significance of procurement systems that are flexible, accountable, and capable of functioning under conditions of uncertainty and urgency, traits that are indispensable in humanitarian supply chains. The prioritization of ML8 thus reflects a broader consensus in the literature regarding its strategic importance in enabling efficient, ethical, and responsive humanitarian supply chain operations.

The second and third highest rankings were assigned to empowerment of emergency teams (ET4) and social media and communication tools (TI3), with preference values of 0.769 and 0.766, respectively. These sub-factors underscore the practical importance of equipping field teams with autonomy and decision-making capabilities, as well as the use of fast and accessible communication platforms for coordination and real-time updates. Similar conclusions were drawn by Adana, et al. [33], who underlined the importance of decentralized decision-making and information flow during humanitarian crises. Among the top five were also stakeholder cooperation and coordination (CS2) and planning & organizing (ML1). Their strong rankings confirm that collaboration across agencies, along with structured planning, plays a significant role in managing logistics complexity in disaster situations. Liu and Shi [34] similarly highlighted inter-organisational coordination and proactive planning as core pillars for effective disaster response logistics.

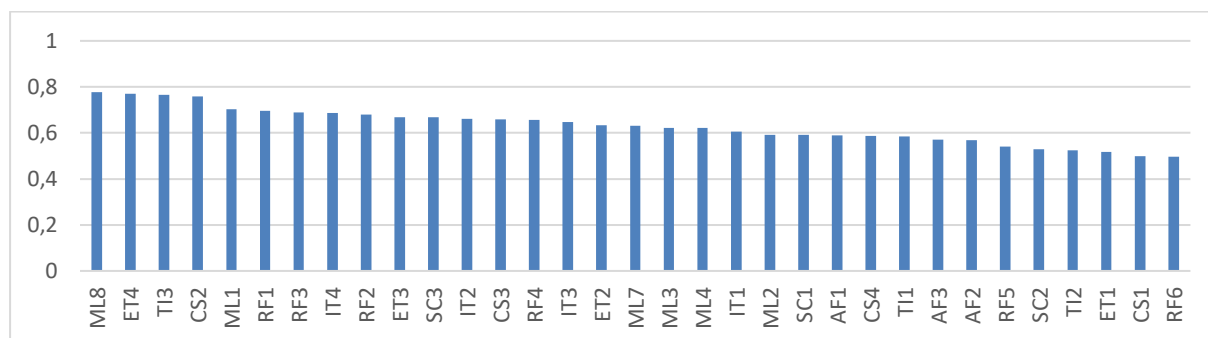


Figure 2. Prevalence values of CSFs

Table 8. The rank of critical success factors of humanitarian supply chains

Sub-Criteria	D ⁺	D ⁻	Preference Value	Rank
Planning and organizing (ML1)	0.225	0.535	0.704	5
Strategic planning for emergency relief (ML2)	0.296	0.43	0.592	21
Top management support (ML3)	0.181	0.297	0.621	18
Change management (ML4)	0.186	0.305	0.621	19
Growth and continuous improvement (ML7)	0.27	0.462	0.631	17
Procurement and donation management (ML8)	0.154	0.541	0.778	1
Inter-agency coordination (CS1)	0.316	0.314	0.498	32
Stakeholder cooperation and coordination (CS2)	0.162	0.51	0.759	4
Supplier and customer relationship mgmt (CS3)	0.211	0.407	0.659	13
Cross-functional teams (CS4)	0.236	0.337	0.588	24
Staff training and education (ET1)	0.272	0.292	0.518	31
Technical skills and retention (ET2)	0.208	0.36	0.634	16
Need-based stakeholder training (ET3)	0.241	0.486	0.669	10
Empowerment of emergency teams (ET4)	0.157	0.523	0.769	2
ICT and information systems (TI1)	0.344	0.483	0.584	25
System integration & architecture (TI2)	0.272	0.301	0.525	30
Social media & communication tools (TI3)	0.163	0.535	0.766	3
Rapid needs assessment (AF1)	0.343	0.493	0.590	23
Pre-warning & early warning (AF2)	0.211	0.279	0.569	27
Forecasting accuracy (AF3)	0.287	0.382	0.571	26
Relief materials & equipment (RF1)	0.174	0.399	0.696	6
Financial planning & transparency (RF2)	0.19	0.404	0.680	9
Effective use of resources (RF3)	0.202	0.449	0.690	7
Inventory management (RF4)	0.212	0.406	0.657	14
Economic conditions (RF5)	0.259	0.305	0.541	28
Cost efficiency (RF6)	0.268	0.264	0.496	33
Road and transport network (IT1)	0.338	0.518	0.605	20
Fleet and logistics coordination (IT2)	0.27	0.527	0.661	12
Accessibility of hospitals (IT3)	0.168	0.309	0.648	15
Quick restoration of connectivity (IT4)	0.159	0.348	0.686	8
Socio-cultural factors (SC1)	0.228	0.331	0.592	22
Political context (SC2)	0.316	0.357	0.530	29
Religion of beneficiaries (SC3)	0.206	0.413	0.667	11

On the other hand, several sub-criteria consistently show lower preference values, such as cost efficiency (RF6), inter-agency cooperation (CS1), staff training and education (ET1), and system integration and architecture (TI2). Cost efficiency (RF6) ranks the lowest with a value of 0.496. In commercial supply chains, cost is a key metric. Cost is a crucial parameter that is evaluated in commercial supply chains. However, in humanitarian supply chains, the emphasis frequently turns to speed and reach. Reducing costs might come into conflict with the need to respond quickly and equitably. As emphasized by [Lewin, et al. \[35\]](#), cost efficiency may not align well with humanitarian goals, particularly during emergency response phases. Furthermore, Inter-agency coordination (CS1) also ranks low with a score of 0.498. Coordination between NGOs, governments, and international organizations is often fragmented. Differences in goals, protocols, and communication standards can lead to inefficiencies in operations. [Grange, et al. \[36\]](#) claimed that although coordination is necessary, it is often difficult to establish in practice, particularly under time constraints.

Another sub-criterion that ranks low is staff training and education (ET1), which has a value of 0.518. Although capacity building is essential for long-term resilience, the results are not always immediate. In urgent crises, corporations may prioritise sending experienced individuals over investing in training. Nyarko, et al. [37] observed that humanitarian organizations frequently lack formal training programs due to financial and time constraints. System integration and architecture (TI2) has a preference rating of 0.525. It reflects the persistent issue with fragmented IT systems in the real world. Many humanitarian actors rely on distinct platforms that lack interoperability. According to Jayawardene, et al. [38], poor information system integration can limit the speed and accuracy of disaster decision-making. Additionally, while these sub-criteria are undoubtedly important within the broader framework of humanitarian supply chains, their lower rankings suggest that operational immediacy, coordination within specific teams, and resource mobilisation often take precedence during critical phases of humanitarian relief. However, do not diminish their significance; instead, they indicate a gap between strategic importance and perceived short-term impact, indicating the need for further research and policy activities focused at reinforcing their function through improved integration, investment, and practical frameworks.

4. Conclusion

This study proposed a hybrid decision-making framework based on Intuitionistic Fuzzy AHP and Intuitionistic Fuzzy TOPSIS to identify and prioritise Critical Success Factors (CSFs) in humanitarian supply chain management. By evaluating 33 sub-criteria under eight main criteria, the findings indicate that operational dimensions, such as procurement and donation management, emergency team empowerment, and effective communication, are the most critical for disaster response. These results highlight the importance of agility, coordination, and field-level execution. However, technological and strategic planning aspects received lower practical rankings, suggesting a gap between conceptual significance and real-world applicability. Practically, the proposed framework offers structured guidance for enhancing preparedness and improving supply chain performance. However, this study has limitations, including the restricted number and profile of expert respondents, the potential for subjective bias, and a geographical focus limited to Indonesia. Future research should involve a more diverse expert panel across regions and organisations, incorporating dynamic methods such as DEMATEL or ISM to explore the interdependencies among CSFs. Developing real-time decision-support systems could further enhance the practical utility of the model in humanitarian operations.

Declarations

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