Open Journal of Social Sciences, 2025, 13(6), 1-19
https://www.scirp.org/journal/jss
ISSN Online: 2327-5960
ISSN Print: 2327-5952

Influencing Factors of Emergency Supply Chain Digitization from the Perspective of Sustainable Development

Zirui Zhou, Cejun Cao*

School of Management Science and Engineering, Chongqing Technology and Business University, Chongqing, China
Email: *caocejun0601@tju.edu.cn

How to cite this paper: Zhou, Z. R., & Cao, C. J. (2025). Influencing Factors of Emergency Supply Chain Digitization from the Perspective of Sustainable Development. *Open Journal of Social Sciences, 13,* 1-19.
https://doi.org/10.4236/jss.2025.136001

Received: May 27, 2025
Accepted: June 7, 2025
Published: June 10, 2025

Abstract

In order to expand the understanding of influencing factors of emergency supply chain digitalization, the focus of this research is placed on identifying these factors from the perspective of sustainable development. A comprehensive analysis is conducted across six dimensions—policy, society, economy, technology, organization, and security—to summarize the relevant influencing factors. Then, an Analytic Network Process model is constructed, and the model is solved using SuperDecisions software. Finally, relevant policy recommendations are proposed from the six dimensions, providing new insights into the identification of influencing factors regarding emergency supply chain digitalization from the viewpoint of sustainable development. Research findings indicate that technology and economy are the key factors influencing emergency supply chain digitalization. Secondly, innovation capability, responsiveness, resource investment, and IT level have significant impacts on emergency supply chain digitalization. Thirdly, emergency supply chain digitalization involves complex interactions across multiple dimensions, including policy, society, economy, technology, organization, and security. Therefore, future efforts should emphasize the coordinated development across these dimensions.

Keywords

Emergency Supply Chains, Digital Technology, Sustainable Development, Influencing Factors, Analytic Network Process

1. Introduction

In the digital era, emerging information technologies—including cloud computing, artificial intelligence, the Internet of Things, blockchain and digital twin are rapidly transforming logistics service scenarios. This transformation is clearly evidenced by the extensive application of digital technologies across a wide range of logistics activities, thereby accelerating the digitalization of supply chains. In the field of emergency management, traditional emergency supply chains often focus only on short-term efficiency while neglecting long-term environmental, social, and economic impacts. Digital technologies not only provide new insights but also technical tools for addressing relevant issues in traditional emergency supply chain management. Dubey et al. (2020), Chen & Lin (2021), and Longo et al. (2023) also emphasized the necessity and urgency of applying digital technologies to address challenges in emergency supply chain management. Therefore, studies on emergency supply chain digitalization become particularly important.

Theoretical studies indicate that most researchers use empirical studies and modelling approaches to investigate the issues-related to emergency supply chain digitalization from an operational standpoint. However, what are the key factors influencing emergency supply chain digitalization remains open question. Only by clarifying these critical factors and their connections can decision-makers effectively allocate available resources and help managers formulate appropriate strategies, thereby improving the sustainability of emergency supply chain digitalization. By leveraging the insights of Corbett et al. (2022), Anjomshoae et al. (2023), and Chowdhury et al. (2024), the sustainable development theory is verified to be a new perspective to explore the influencing factors of emergency supply chain digitalization. In this context, identifying influencing factors and internal relationships of emergency supply chain digitalization from the perspective of sustainable development has become an urgent and promising research problem.

In recent years, scholars have conducted meaningful explorations on emergency supply chain digitalization. For example, regarding the multi-objective spatial optimization location problem of urban emergency rescue facilities, Zhao & Liu (2018) developed a user-friendly decision support tool that integrates multi-objective optimization algorithms, artificial intelligence techniques, and GIS technology, aiming to facilitate the optimization of emergency facility locations in large urban areas. From a data-driven perspective, Liu et al. (2020) constructed a single-objective linear programming model for emergency logistics network in the context of the COVID-19 pandemic. This model aims to minimize the emergency cost over the decision period and is solved using a hybrid enumeration search and genetic algorithm. Longo et al. (2023) proposed a simulation-based decision framework that leverages the digital supply chain twin paradigm to enhance resilience and sustainability in response to COVID-like crises. Dubey et al. (2020) applied blockchain technology to establish swift trust and cooperation among disaster relief actors and investigated how blockchain influences supply chain transparency among these actors, aiming to improve the traceability and transparency of material and financial flows in disaster relief operations. Chen & Lin (2021) leveraged the advantages of big data in processing massive amounts of information to construct an emergency logistics resource scheduling model in the aftermath of earthquakes. This model considers the coordination and scheduling of multiple transportation modes. A genetic algorithm was employed to solve the model, aiming to improve the accuracy of emergency resource allocation, shorten the delivery time of emergency supplies, and reduce property losses.

In the field of sustainable emergency supply chains, Karuppiah et al. (2021) highlighted five critical challenges in sustainable humanitarian supply chains: facility location selection, short lead times for emergency supplies, spread of rumor, rapid emergence of new clusters, and doubt concerning the available remedy, while identifying public-private partnerships as the optimal strategy. Through the development of a decision support model, Chowdhury et al. (2024) identified the absence of contingency planning, corruption and political interference, and inadequate social-environment awareness as critical barriers to sustainable humanitarian supply chain management. Anjomshoae et al. (2023) made a systematic review of sustainable humanitarian supply chains, revealing that their sustainability encompasses multiple dimensions, including supply network configuration, coordination mechanisms, partnership, and performance measurement. By summarizing a 1-day workshop on sustainable humanitarian supply chain management, Corbett et al. (2022) concluded that the optimization of evaluation metrics and incentive mechanisms, along with the coordination between local and global organizations' functions, constitute critical factors influencing the effective integration of sustainability into humanitarian operations. Patil et al. (2021) conducted an in-depth analysis of the challenges in achieving sustainability within humanitarian medical supply chains, highlighting the critical need for stakeholders to address material, operational and logistical issues, while the study proposes long-term collaboration and the adoption of cash-based donations as effective alternatives to traditional product donation approaches.

The Analytic Network Process (ANP) is a multi-criteria decision-making method that accounts for interdependence among factors. It is used to solve complex weight determination problems. By constructing a network-based model, ANP can more realistically reflect the feedback and interrelationships among factors in actual decision-making, thus providing a systematic analytical approach for examining the interconnections among influencing factors of emergency supply chain digitalization from the perspective of sustainable development. This method has received extensive attention from scholars in various fields. For example, Saputro et al. (2023) used the Panjalu region of Indonesia as a case study and integrated multidimensional scaling with ANP to examine sustainable strategies for rural tourism development in the area. Zhou et al. (2019) introduced probabilistic linguistic term sets to gather opinions in a short time frame, applied fault tree analysis to evaluate failures, and used ANP to derive standard weights for the severity of potential consequences, aiming to select the optimal relief plan to reduce losses during emergencies. Peng et al. (2022) integrated a consistent linguistic fuzzy preference relation-based ANP with the fuzzy TOPSIS method to construct a comprehensive performance evaluation model for rural homestays, and conducted an empirical analysis on rural homestays in Zhejiang Province. The goal was to fill the research gap in homestay performance and enhance their competitiveness and sustainability in the post-COVID-19 era.

According to the aforementioned literature, the following conclusions can be drawn. Firstly, most scholars have focused on applying various digital technologies to address operational-level issues within emergency supply chains. Although some studies have explored the digitalization of emergency supply chains, research specifically examining the influencing factors of emergency supply chain digitalization remains limited. Secondly, current research on sustainable emergency supply chains primarily centers on using quantitative methods such as mathematical programming to address emergency resource allocation and disaster waste management, exploring influencing factors of emergency supply chains from the perspective of sustainable development is relatively scarce. Thirdly, the ANP has been widely applied in theoretical enhancements and practical extensions. However, its application in the field of humanitarian supply chains, especially in identifying influencing factors of emergency supply chain digitalization from the perspective of sustainable development is still inadequate. To address the above issues, this study first identifies influencing factors of emergency supply chain digitalization from a sustainable development perspective by literature review and expert interviews. Then, the ANP is used to evaluate the importance or weights of these influencing factors from six dimensions: policy, society, economy, technology, organization, and security. Finally, targeted recommendations are proposed to provide a theoretical foundation for advancing the digitalization of emergency supply chains from a sustainability perspective.

2. Analytic Network Process

The ANP, developed by Professor Saaty of the United States as an extension of the Analytic Hierarchy Process (AHP), is designed to address the complex evaluation of influencing factors. ANP consists of a control layer and a network layer. The control layer includes the decision goal and decision criteria, while the network layer composes internal and external elements under various criteria that exhibit interdependencies. ANP overcomes the limitation of AHP, which only presumes elements are mutually independent and organized in a strict hierarchical structure. It enables systematic pairwise comparisons of all elements under multiple criteria, thereby enhancing analytical rigor and strengthening real-world applicability for decision-making contexts. In this regard, ANP offers an effective methodological framework for analyzing influencing factors and their interrelationships of emergency supply chain digitalization from the perspective of sustainable development. The ANP implementation process in emergency supply chain digitalization entails five key steps: identification of influencing factors, construction of the network hierarchy structure, construction of the judgment matrix, development of the unweighted and weighted supermatrix, and calculation of the limit matrix.

2.1. Identification of Influencing Factors

Through a comprehensive literature review and expert interviews, influencing factors of emergency supply chain digitalization from the perspective of sustainable development are identified across multiple dimensions. These factors are further refined and validated based on expert feedback, resulting in a finalized set of influencing factors. In addition, the experts evaluate the pairwise interrelationships among these factors influencing emergency supply chain digitalization, thereby constructing a relationship matrix that reflects the dependencies among the influencing factors.

2.2. Construction of the Network Hierarchy Structure

The identified influencing factors of emergency supply chain digitalization from the perspective of sustainable development are initially categorized into control layer and network layer components. The control layer consists of the goal and decision criteria, with all criteria being directly governed by the goal element. This layer serves three primary functions: organizing the hierarchical structure, establishing weight assignment mechanisms through defined criteria and evaluation standards, and guiding the computational processes of the network layer to ensure the system's coherence and scientific rigor. While decision criteria are optional in the control layer, but the presence of at least one goal element is mandatory, thereby forming a typical hierarchical structure. The network layer comprises subordinate influencing factors controlled by the control layer, forming an internally interdependent network structure. It focuses on modeling and calculating the specific elements and their interrelationships, handling the actual data processing and information transfer between hierarchical levels.

The key difference lies in that the control layer emphasizes the macrolevel framework design and strategic control, functioning at the decision-making level, whereas the network layer concentrates on micro-level node connections and weight calculations, operating at the execution and computational level. Through their coordinated interaction, the model can effectively achieve hierarchical decomposition and comprehensive multi-factor evaluation.

In this context, the network hierarchy structure is drawn. Each cluster contains its specific elements, with lines representing the connections between node elements. The element at the tail of an arrow exerts the influence on the one at the head, indicating two forms of dependency: external and internal.

2.3. Construction of the Judgment Matrix

1) Expert Scoring

Based on the relationship matrix obtained through expert interviews, a series of judgment matrices are constructed to evaluate the relative importance among all influencing factors. Then, additional experts are invited to assign scores to the elements in these matrices. The collected data undergo consistency verification to ensure the reliability and validity of the judgment matrices.

2) Construction of the Unweighted Supermatrix

Following the method used for constructing the judgment matrices, all relevant matrices are constructed and calculated to derive their corresponding normalized eigenvectors. These normalized eigenvectors, obtained from the pairwise comparison matrices, are then aggregated to form the unweighted supermatrix.

3) Construction of the Weighted Supermatrix

By aggregating the normalized weights derived from the judgment matrices of all primary indicators, the cluster weight matrix can be obtained. Multiplying this cluster weight matrix with the previously constructed unweighted supermatrix yields the weighted supermatrix.

2.4. Calculation of the Limit Supermatrix

In ANP, the introduction of feedback mechanisms and interdependencies increases the complexity of determining indicator weights. The relative importance between two influencing factors can be evaluated through both direct and indirect comparisons. For instance, W_{ij} denotes the direct comparison between indicators i and j, while $\sum W_{ik} W_{kj}$ reflects their indirect relationship mediated by other indicators. These intricate indirect relationships are captured through iterative calculations of the supermatrix. Therefore, the weights of indicators are ultimately derived by computing the limit supermatrix, which is obtained by raising the weighted supermatrix to successive powers until convergence, i.e., $W = lim W^k$. This process can be executed using the SuperDecisions software.

3. Analytic Network Model and Solution for Emergency Supply Chain Digitalization

3.1. Model Construction

1) Identification of Influencing Factors for Emergency Supply Chain Digitalization from the Perspective of Sustainable Development

Firstly, this paper concludes the indicators proposed in the existing literature. Then, insights from experts in Table 1 in the field of public safety and emergency management, and supply chain management are extended to revise or modify the indicators. In this context, this study categorizes the key influencing factors of emergency supply chain digitalization into six categories comprising seventeen indicators from the perspective of sustainable development.

Specifically, the first category is policy, including strategic planning and standardization construction. The second factor is society, including trust level, responsiveness, and coordination mechanism. The third one is the economic factor, including resource investment and cost-benefit. The fourth one is the technological factor, including innovation capability, IT level, data sharing efficiency, and intelligence level. The fifth factor is organization, including organizational

Table 1. Expert information.

Expert	Education background	Gender	Academic title	Research interest
Expert 1	Doctoral degree	Male	Professor	Emergency supply chain
Expert 2	Doctoral degree	Male	Professor	Sustainable supply chain
Expert 3	Doctoral degree	Male	Associate professor	Digital supply chain
Expert 4	Doctoral degree	Female	Associate professor	Emergency supply chain
Expert 5	Doctoral degree	Male	Associate professor	Sustainable humanitarian supply chain

collaboration, resource integration, and strategic implementation capability. The sixth factor is security, including data security, system reliability, and environmental risk control.

Thus, influencing factors of emergency supply chain digitalization and their specific meanings are presented in the following Table 2.

Table 2. Influencing factors of emergency supply chain digitalization from the perspective of sustainable development.

Primary indicators	ID	Secondary indicators	ID	Definition	Source
Policy	A	Strategic planning	A1	Whether the digitization of emergency supply chains explicitly incorporates sustainable development goals to ensure that resource allocation, technology application, and long-term social and environmental benefits are well coordinated.	Van Wassenhove (2006) Bag et al. (2020) Chowdhury et al. (2024)
		Standardization construction	A2	Whether digital technology regulations and management standards are unified and embedded with sustainable indicators such as green and low-carbon criteria to ensure alignment with long-term development requirements.	Behl & Dutta (2019) Chowdhury et al. (2024)
Society	B	Trust level	B1	Level of acceptance of digital emergencies and ethics of social justice and sustainability among businesses, governments and citizens, etc.	Woldt et al. (2019)
		Responsiveness	B2	Speed of response and efficiency of material mobilization of social agents in emergency situations.	Woldt et al. (2019)
		Coordination mechanism	B3	Mechanisms for cooperation between different social actors and for sharing resources.	Anjomshoae et al. (2023)
Economy	C	Resource investment	C1	Whether the allocation of financial, technical and other resources in the digitization of emergency supply chains is sufficient and whether it can guarantee the sustainable operation of the system and take into account the long-term benefits, etc.	Patil et al. (2021)
		Cost-benefit	C1	Whether the cost of digital construction and operation is reasonable and can maximize economic, social, and environmental benefits while enhancing emergency efficiency.	Patil et al. (2021) Damoah et al. (2021)
Technology	D	Innovation capability	D1	Whether enterprises or industries can continuously develop and apply new technologies during the digital transformation process.	Dubey et al. (2020)
		IT level	D2	The advancement and reliability of digital infrastructure, to meet the dual requirements of efficient response and long-term sustainable development.	Najjar et al. (2019) Dubey et al. (2020)
		Data sharing efficiency	D3	Whether the real-time and accuracy of cross-departmental and cross-level data collaboration can support optimized resource allocation and fair distribution.	Zhao & Liu (2018) Dubey et al. (2020)
		Intelligence level	D4	The depth of AI, IoT, and other technology applications in achieving precise forecasting, dynamic optimization, and resource waste reduction.	Najjar et al. (2019)
Organization	E	Organizational collaboration	E1	Whether digital platforms enable seamless collaboration among subjects in emergency supply chains, forming a unified and efficient sustainable action network.	Karuppiah et al. (2021) Tseng et al. (2021) Anjomshoae et al. (2023)

Continued

		Resource integration	E2	Whether all organizations can optimize the allocation of dispersed resources like manpower and materials in the digitalization process to improve overall rescue efficiency and long-term resilience.	Anjomshoae et al. (2023) Kashav & Garg (2024)
		Strategic implementation capability	E3	Whether the organizational structure and processes adapt to digital strategies, ensuring sustainable development goals are effectively transformed into specific actions and outcomes.	Karuppiah et al. (2021) Corbett et al. (2022)
Safety	F	Data security	F1	The protection strength of sensitive data in the digitalization of emergency supply chains, and whether it can prevent leaks during sharing and collaboration while safeguarding the rights of all parties.	Dubey et al. (2020)
		System reliability	F2	The stability and interference resistance of digital platforms, ensuring sustainable operation and maintenance of key functions under extreme environments.	Longo et al. (2023)
		Environmental risk control	F3	Whether the digital construction process can reduce energy consumption and pollution to avoid secondary environmental hazards.	Rehman Khan et al. (2022) Chowdhury et al. (2024)

To explore the interrelationships among influencing factors, experts have to assess the existence and nature of dependencies between distinct elements. Through surveys and interviews with multiple experts, these interrelationships can be systematically identified in the form of dependency matrix regarding influencing factors of emergency supply chain digitalization, as shown in Table 3.

Table 3. Dependency matrix regarding influencing factors.

	A1	A2	B1	B2	B3	C1	C2	D1	D2	D3	D4	E1	E2	E3	F1	F2	F3
A1	0	1	0	1	1	1	1	0	0	1	0	1	1	1	1	0	0
A2	1	0	0	0	1	0	0	0	1	1	0	1	1	1	1	1	1
B1	0	0	0	1	1	0	0	0	0	1	0	1	1	1	0	0	0
B2	0	0	1	0	1	1	0	1	1	1	1	1	1	1	0	1	0
B3	0	0	1	1	0	0	0	1	1	1	1	1	1	1	0	1	0
C1	1	0	1	1	1	0	1	1	1	0	1	0	1	1	0	0	1
C2	1	0	0	1	0	1	0	1	1	1	1	1	1	1	0	1	1
D1	1	0	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1
D2	0	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	0
D3	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1	1	1
D4	0	0	0	1	1	1	1	1	1	1	0	1	1	1	1	1	0
E1	0	0	1	1	1	0	1	0	1	1	1	0	1	1	1	1	0
E2	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1
E3	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
F1	1	1	0	0	0	0	0	1	1	1	1	1	0	1	0	1	1
F2	0	1	0	1	1	0	1	1	1	1	1	1	0	1	1	0	0
F3	0	1	0	1	1	1	1	0	0	1	0	1	1	1	1	0	0

According to the obtained interrelationships among influencing factors, the SuperDecisions software can be used to generate a visual representation of the relationships among the elements, as shown in Figure 1.

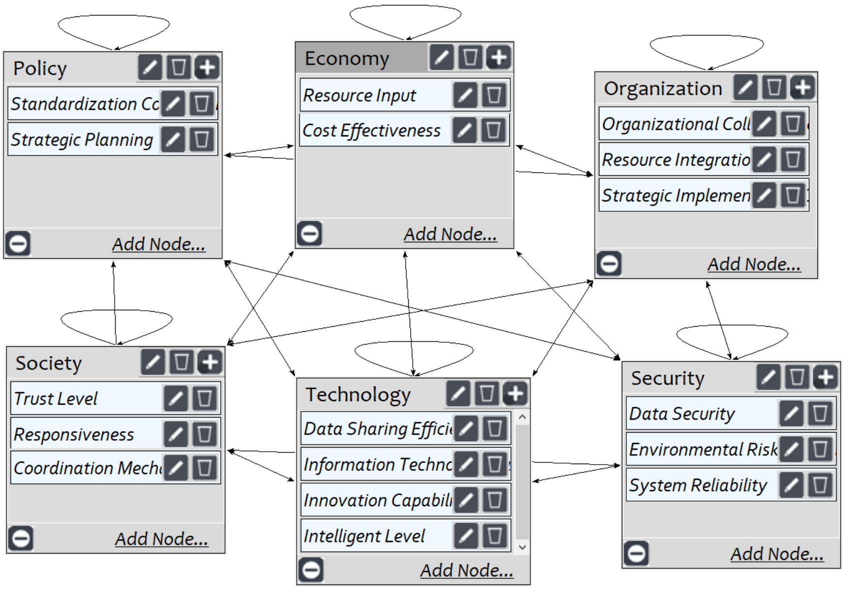

Figure 1. Influencing factors relationships.

2) Construction of the Network Hierarchy Structure

According to the ANP, the identified factors influencing the digitalization of emergency supply chains from a sustainable development perspective are categorized into the control layer and network layer, respectively. Based on the relationships among these factors as outlined in the dependency matrix, the network hierarchy structure is subsequently constructed, as shown in Figure 2.

3) Matrix Construction

Combing the obtained network hierarchy structure, the importance judgment matrices for all influencing factors are first constructed through expert interviews. When these matrices passed a consistency check, the complete set of data for the importance of factors influencing the digitalization of emergency supply chains is obtained. By combining the normalized vectors of all the importance judgment matrices, the unweighted supermatrix can be constructed, as shown in Table 4.

By normalizing the vector of scores generated from expert evaluations of the importance judgment matrix across all dimensional indicators, the cluster weight matrix can be derived, as shown in Table 5.

By multiplying the cluster weight matrix with the unweighted supermatrix, the weighted supermatrix can be obtained, as shown in Table 6.

4) Solution of the limit matrix

Based on the weighted supermatrix derived above, the limit matrix can be obtained by multiplying the weighted supermatrix with itself infinitely, as shown in Table 7. The limit matrix presents the final weights of factors influencing the digitalization of emergency supply chains from the perspective of sustainable development.

In conclusion, the final results are shown in Table 8.

Table 4. Unweighted supermatrix.

	A1	A2	B1	B2	B3	C1	C2	D1	D2	D3	D4	E1	E2	E3	F1	F2	F3
A1	0.00	1.00	0.00	1.00	0.75	1.00	1.00	0.00	0.00	0.80	0.00	0.14	0.75	0.67	0.80	0.00	0.83
A2	1.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	1.00	0.20	0.00	0.86	0.25	0.33	0.20	1.00	0.17
B1	0.00	0.00	0.00	0.83	0.67	0.00	0.00	0.00	0.00	0.63	0.00	0.63	0.63	0.63	0.00	0.00	0.00
B2	0.00	0.00	0.75	0.00	0.33	1.00	0.00	0.83	0.75	0.24	0.67	0.24	0.24	0.24	0.00	0.83	0.20
B3	0.00	0.00	0.25	0.17	0.00	0.00	0.00	0.17	0.25	0.14	0.33	0.14	0.14	0.14	0.00	0.17	0.80
C1	0.83	0.00	1.00	0.88	1.00	0.00	1.00	0.86	0.13	0.00	0.80	0.00	0.83	0.13	0.00	0.00	0.00
C2	0.17	0.00	0.00	0.13	0.00	1.00	0.00	0.14	0.88	1.00	0.20	1.00	0.17	0.88	0.00	1.00	0.00
D1	0.83	0.00	0.00	0.58	0.58	0.66	0.58	0.00	0.74	0.65	0.65	0.58	0.58	0.58	0.58	0.58	0.58
D2	0.00	0.80	0.00	0.23	0.23	0.26	0.23	0.65	0.00	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
D3	0.17	0.20	0.00	0.13	0.13	0.00	0.13	0.23	0.17	0.00	0.12	0.13	0.13	0.13	0.13	0.13	0.13
D4	0.00	0.00	0.00	0.06	0.06	0.08	0.06	0.12	0.09	0.12	0.00	0.06	0.06	0.06	0.06	0.06	0.06
E1	0.00	0.00	0.70	0.70	0.70	0.00	0.70	0.00	0.70	0.70	0.70	0.00	0.86	0.83	0.75	0.67	0.80
E2	0.75	0.83	0.19	0.19	0.19	0.86	0.19	0.89	0.19	0.19	0.19	0.83	0.00	0.17	0.00	0.00	0.00
E3	0.25	0.17	0.11	0.11	0.11	0.14	0.11	0.11	0.11	0.11	0.11	0.17	0.14	0.00	0.25	0.33	0.20
F1	0.88	0.67	0.00	0.00	0.00	0.00	0.00	0.70	0.70	0.70	0.70	0.70	0.00	0.70	0.00	0.75	0.88
F2	0.00	0.24	0.00	0.83	0.67	0.00	1.00	0.21	0.21	0.21	0.21	0.21	0.00	0.21	0.20	0.00	0.13
F3	0.13	0.09	0.00	0.17	0.33	0.00	0.00	0.08	0.08	0.08	0.08	0.08	0.00	0.08	0.80	0.25	0.00

Table 5. Cluster weight matrix.

	Policy	Society	Economy	Technology	Organization	Security
Policy	0.299	0.070	0.049	0.088	0.049	0.070
Society	0.000	0.027	0.079	0.438	0.079	0.027
Economy	0.130	0.308	0.269	0.149	0.269	0.308
Technology	0.448	0.431	0.436	0.234	0.436	0.431
Organization	0.038	0.042	0.135	0.037	0.135	0.042
Security	0.084	0.121	0.032	0.055	0.032	0.121

Table 6. Weighted supermatrix.

	A1	A2	B1	B2	B3	C1	C2	D1	D2	D3	D4	E1	E2	E3	F1	F2	F3
A1	0.00	0.34	0.00	0.07	0.05	0.05	0.05	0.00	0.00	0.07	0.00	0.01	0.04	0.03	0.08	0.00	0.08
A2	0.30	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.09	0.02	0.00	0.04	0.01	0.02	0.02	0.07	0.02
B1	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.27	0.00	0.05	0.05	0.05	0.00	0.00	0.00
B2	0.00	0.00	0.05	0.00	0.01	0.08	0.00	0.40	0.33	0.10	0.32	0.02	0.02	0.02	0.00	0.02	0.01
B3	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.08	0.11	0.06	0.16	0.01	0.01	0.01	0.00	0.00	0.03
C1	0.11	0.00	0.82	0.27	0.31	0.00	0.29	0.14	0.02	0.00	0.13	0.00	0.23	0.03	0.00	0.00	0.00
C2	0.02	0.00	0.00	0.04	0.00	0.28	0.00	0.02	0.13	0.15	0.03	0.27	0.05	0.24	0.00	0.31	0.00

Continued

D1	0.37	0.00	0.00	0.25	0.25	0.30	0.27	0.00	0.17	0.15	0.17	0.25	0.26	0.25	0.37	0.25	0.36
D2	0.00	0.41	0.00	0.10	0.10	0.12	0.11	0.17	0.00	0.05	0.06	0.10	0.10	0.10	0.15	0.10	0.14
D3	0.07	0.10	0.00	0.06	0.06	0.00	0.06	0.06	0.04	0.00	0.03	0.06	0.06	0.06	0.09	0.06	0.08
D4	0.00	0.00	0.00	0.03	0.03	0.04	0.03	0.03	0.02	0.03	0.00	0.03	0.03	0.03	0.04	0.03	0.04
E1	0.00	0.00	0.08	0.03	0.03	0.00	0.10	0.00	0.03	0.03	0.03	0.00	0.12	0.11	0.05	0.03	0.05
E2	0.03	0.04	0.02	0.01	0.01	0.12	0.03	0.04	0.01	0.01	0.01	0.11	0.00	0.02	0.00	0.00	0.00
E3	0.01	0.01	0.01	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.02	0.01	0.01
F1	0.07	0.06	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04	0.02	0.00	0.02	0.00	0.09	0.15
F2	0.00	0.02	0.00	0.10	0.08	0.00	0.04	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.04	0.00	0.02
F3	0.01	0.01	0.00	0.02	0.04	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.15	0.03	0.00

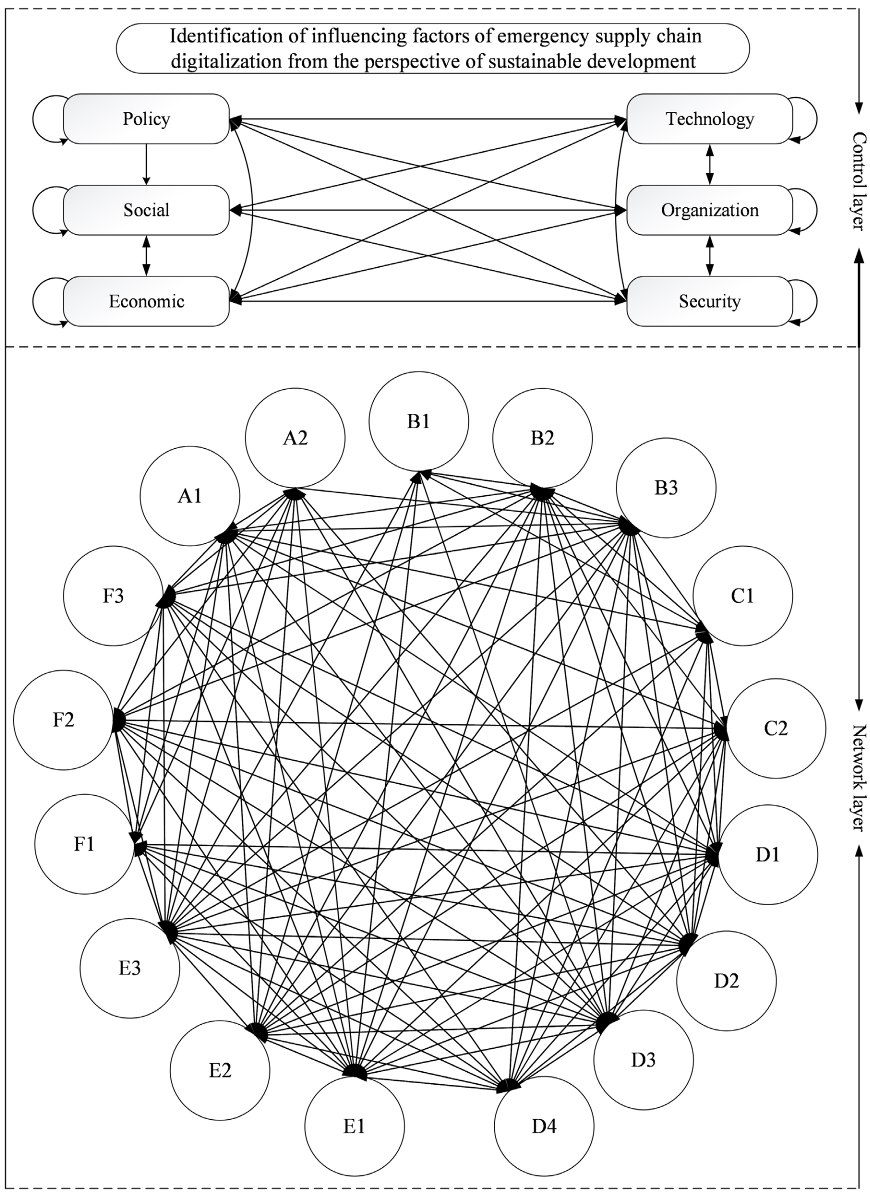

Figure 2. Network hierarchy structure.

Table 7. Limit supermatrix.

	A1	A2	B1	B2	B3	C1	C2	D1	D2	D3	D4	E1	E2	E3	F1	F2	F3
A1	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
A2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
B1	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
B2	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
B3	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
C1	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
C2	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
D1	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
D2	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
D3	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
D4	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
E1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
E2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
E3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
F1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
F2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
F3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table 8. Final weights of influencing factors.

Indicators		Primary indicator	Secondary indicator	Ranking
Policy	Strategic planning	0.069	0.041	8
	Standardization construction		0.027	10
Society	Trust level	0.196	0.020	14
	Responsiveness		0.140	2
	Coordination mechanism		0.036	9
Economy	Resource investment	0.227	0.134	3
	Cost-benefit		0.093	5
Technology	Innovation capability	0.372	0.193	1
	IT level		0.106	4
	Data sharing efficiency		0.047	7
	Intelligence level		0.026	13
Organization	Organizational collaboration	0.073	0.014	15
	Resource integration		0.011	17
	Strategic implementation capability		0.048	6
Safety	Data security	0.063	0.026	12
	System reliability		0.027	11
	Environmental risk control		0.011	16

3.2. Result Analysis

According to Table 8, the importance of control layer factors influencing the digitalization of emergency supply chains from a sustainable development standpoint follows this descending order: technology, economy, society, organization, policy, and security. The importance of network layer factors follows this descending order: innovation capability, responsiveness, resource investment, IT level, cost-benefit, strategic implementation capability, data sharing efficiency, strategic planning, coordination mechanism, standardization construction, system reliability, data security, intelligence level, trust level, organizational coordination, environmental risk control, and resource integration.

In Table 8, the varying weights of influencing factors of emergency supply chain digitalization reflect their differential importance or prioritization when decision-makers develop emergency management strategies in practice. Indicators with relatively low wights, such as resource integration and environmental risk control, should not be considered negligible. Their lower weight values indicate a reduced priority as evaluated by experts within the specific context of this study. In practical applications, the significance of these factors may depend on the circumstance, industry focus, or regional priorities. Therefore, decision-makers should interpret them with contextual sensitivity and dynamically adjust their emphasis based on the actual needs of the implementation environment.

In the control layer, technology and economy exert the most immediate influence on the digitalization of emergency supply chains from a sustainable development perspective. The adaptation of technological applications with economic feasibility often needs to be balanced to provide stable support for the sustainable development of emergency supply chains. The integration of a long-term evaluation mechanism within the system enables assessment of whether digitalization-related investments substantively improve emergency response efficiency, thereby avoiding ineffective expenditure. Overemphasizing advanced technologies while neglecting implementation costs or operational constraints may result in systemic inefficiencies. Conversely, excessive budget constraints prioritizing short-term gains can severely compromise system flexibility and long-term scalability.

In the network layer, factors interact dynamically, with innovation capability emerging as the pivotal factor. Digital innovation capability plays a vital role in enhancing the efficiency of emergency supply chains. To improve emergency response efficiency, continuous advancement in the technology is imperative. Strategic initiatives such as strengthening digital infrastructure, establishing open data platforms, and integrating intelligent algorithms contribute positively to various emergency scenarios. For example, the Internet of Things facilitates real-time location tracking and condition monitoring of critical supplies. AI algorithms optimize routing to accelerate response times. Blockchain enhances information transparency and traceability to a certain degree. However, these technologies entail significant risks. Overreliance on a single technological solution may cause systemic disruption in the event of unexpected cyberattacks or platform failures.

Therefore, technological upgrades must incorporate rigorous assessment of system stability and recovery capabilities. Proactive establishment of disaster recovery mechanisms and verifiable adaptability to diverse emergency scenarios are critical implementation prerequisites.

Overall, the digitalization of emergency supply chains constitutes a complex system engineering endeavor characterized by significant cross-dimensional network interactions and necessitating multidimensional collaborative advancement. In detail, policy guidance serves as the institutional foundation for the digitalization of emergency supply chains. Social acceptance fosters a favorable implementation circumstance. Economic investment underpins the infrastructure development. Technological innovation propels the transformation and upgrading of emergency supply chains. Organizational collaboration optimizes emergency resource allocation. Security assurance permeates the lifecycle. Future progress in emergency supply chain digitalization demands the dismantling of single-dimensional development constraints and a strategic focus on constructing a multidimensional collaborative ecosystem. This can be facilitated by the synergistic interplay of policy incentives and social engagement, the reciprocal reinforcement of technological innovation and economic investment, and the coordinated advancement of organizational restructuring alongside security assurance. Upon identifying crucial influencing factors, implementing targeted interventions becomes imperative to effectively elevate the level of emergency supply chain digitalization within the framework of sustainable development.

4. Strategies for Enhancing Emergency Supply Chain Digitalization from the Perspective of Sustainable Development

According to the weights in Table 8, it can be seen that technological, economic, and social dimensions are the most important factors influencing emergency supply chain digitalization from a control layer standpoint. Technological, economic, and social influences on the digitalization of emergency supply chains are on a decreasing trend.

4.1. Strategies for Enhancing Emergency Supply Chain Digitalization from a Technological Perspective

1) Strengthen Technological Support and Build a Digitalized Emergency Management System

Technological capability, as the core driving force behind the modernization of emergency supply chains, directly determines the efficiency and precision of disaster response. The heart of emergency supply chain digitalization lies technological integration and innovation in application. Strategic efforts should be directed towards advancing frontier technologies such as artificial intelligence, blockchain, big data, and the Internet of Things. It is essential to support interdisciplinary and cross-sector collaborative research initiatives to strengthen the independent controllability of crucial technologies. Moreover, long-term and stable cooperation mechanisms among enterprises, universities, and academic institutions should be encouraged, with the goal of jointly developing technology innovation platforms that facilitate the seamless integration of digital tools from research and development to practical application.

2) Accelerate the Construction and Promotion of Digital Infrastructure Such as Intelligent Scheduling Systems, Visual Tracking Platforms, and Distributed Data Storage Systems

In terms of standard construction, it is urgent to promote the implementation of unified interface protocols, data format specifications, and platform docking mechanisms to solve issues like platform fragmentation and data silos, thus truly achieving technological interconnectivity, system linkage, and efficient collaboration.

3) Focus on Breakthroughs in Key Technologies Such as Big Data Analysis, AI Prediction, and Blockchain Traceability

Drawing on the successful experience of Zhejiang Province's "Flood Control Brain" system, it is recommended to deploy an intelligent disaster warning platform nationwide. This would enable real-time monitoring of disaster risks and accurate prediction of material needs. On this basis, an emergency technology standard system should be established to ensure data interoperability between different systems, thereby avoiding the formation of information silos.

4.2. Strategies for Enhancing Emergency Supply Chain Digitalization from an Economic Perspective

Digital upgrades often come with high investment and risk. In emergency scenarios, this demands higher efficiency in resource allocation. The government should guide diversified funding to participate in infrastructure construction and digital transformation of emergency supply chains. This can be achieved by encouraging social capital through modes like public-private partnerships. To incentivize participation, differentiated tax exemptions and green credit channels can be explored to ease the digitalization costs for enterprises. A scientific and reasonable cost-benefit evaluation system should be established for the digitalization of emergency supply chains, focusing not only on economic benefits but also on environmental performance and social impact. The goal is to promote forming a "green, low-carbon, and efficient" idea in resource allocation. The government can guide enterprises to explore data-driven cost optimization paths. For instance, enterprises can use digital twin and big data technologies to enhance scheduling efficiency, maximizing resource utilization and minimizing redundancy and waste.

4.3. Strategies for Enhancing Emergency Supply Chain Digitalization from a Social Perspective

Firstly, a multi-entity collaborative governance network needs to be established to improve social mobilization capabilities. Efficient operations of emergency supply chains involve not only governments and enterprises but also social forces. The central government could lead in forming relevant emergency organizations, integrating efforts from enterprises, communities, NGOs, and other parties. Regular cross-entity joint drills should be conducted. Additionally, residents' understanding and support for the digitalization of emergency management system must be enhanced through various channels and forms of popular science education and policy promotion, guiding public participation in volunteer services, information feedback, and material collection. An open platform should be built to encourage diverse entities such as research institutions, social organizations, and industry associations to engage in co-constructing the supply chain, data collaboration, and supervisory feedback, fostering the development of a collaborative governance social mechanism. Using blockchain technology, a trusted disaster information sharing platform can be established to publicly disclose the flow of emergency materials in real-time and eliminate social trust barriers. For private enterprises involved in emergency response, incentives such as tax exemptions or government procurement priorities can be provided. Furthermore, legislation should ensure the legal status of volunteer organizations, clarify their action privileges during emergency response to prevent disordered rescue efforts from causing resource waste. It also should strengthen trust-building across departments and industries. Open and transparent data sharing mechanisms and a strengthened platform liability traceability system can gradually establish a trust-based cooperation mode, enhancing overall collaborative efficiency and social responsiveness.

5. Conclusion

To explore the key influencing factors of emergency supply chain digitalization from the perspective of sustainable development, this study initially identified relevant factors from six dimensions—policy, society, economy, technology, organization, and security through a systematic literature review. Subsequently, based on expert interviews, six primary factors and seventeen secondary factors were screened and finalized. Using the ANP, experts evaluated the interrelationships among these factors and assessed their relative importance within each dimension, thereby quantifying the weight of each factor. Based on the analytical results, this study proposed targeted policy recommendations aimed at addressing issues in the digitalization of emergency supply chains.

Future studies can be extended from the following aspects. Firstly, this paper uses literature review and expert interviews to select 17 influencing factors of emergency supply chain digitalization from the viewpoint of sustainable development. In practice, the digitalization of emergency supply chains is quite complex, the criteria to evaluate influencing factors are different for different decision-makers. In the future, constructing a relatively comprehensive indictors is a promising topic. Secondly, the identified influencing factors and their corresponding weights are initially proposed based on expert judgment and subjective evaluation, without being specifically tailored to any particular national or regional context. In practical applications, these factors and weights are intended to serve as a foundational framework that can be adapted and refined according to the unique characteristics and contextual conditions of different countries or regions. The following work is to concentrate on scenario-dependent influencing factors and the corresponding weights. Thirdly, this study uses ANP to evaluate the influencing factors of emergency supply chain digitalization considering sustainability from a static or short-term perspective. In practice, this approach does not fully capture the evolving nature of emergency supply chain digitalization, just providing a snapshot of the current state. Thus, investigating this problem from a dynamic or time-sensitive perspective is an important direction for future research.

Funding

This paper was partially supported by Higher Education Teaching Reform Research Project of Chongqing Technology and Business University Grant No. 2022113, and Undergraduate Innovation and Entrepreneurship Training Planning Grant No. 202311799012.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Anjomshoae, A., Banomyong, R., Hossein Azadnia, A., Kunz, N., & Blome, C. (2023). Sustainable Humanitarian Supply Chains: A Systematic Literature Review and Research Propositions. *Production Planning & Control, 36,* 357-377. https://doi.org/10.1080/09537287.2023.2273451

Bag, S., Luthra, S., Venkatesh, V. G., & Yadav, G. (2020). Towards Understanding Key Enablers to Green Humanitarian Supply Chain Management Practices. *Management of Environmental Quality: An International Journal, 31,* 1111-1145. https://doi.org/10.1108/meq-06-2019-0124

Behl, A., & Dutta, P. (2019). Humanitarian Supply Chain Management: A Thematic Literature Review and Future Directions of Research. *Annals of Operations Research, 283,* 1001-1044. https://doi.org/10.1007/s10479-018-2806-2

Chen T., & Lin Y. (2021). Design of a Model for the Scheduling of Emergency Logistics Resources after Earthquakes against the Background of Big Data Analysis. *Journal of Earthquake Engineering, 40,* 1343-1349. (In Chinese) https://doi.org/10.3969/j.issn.1000-0844.2018.06.1343

Chowdhury, M. M. H., Paul, S. K., Khan, E. A., & Shakil Mahmud, A. K. M. (2024). A Decision Support Model for Barriers and Optimal Strategy Design in Sustainable Humanitarian Supply Chain Management. *Global Journal of Flexible Systems Management, 25,* 467-486. https://doi.org/10.1007/s40171-024-00394-z

Corbett, C. J., Pedraza-Martinez, A. J., & Van Wassenhove, L. N. (2022). Sustainable Humanitarian Operations: An Integrated Perspective. *Production and Operations Management, 31,* 4393-4406. https://doi.org/10.1111/poms.13848

Damoah, I. S., Ayakwah, A., & Tingbani, I. (2021). Artificial Intelligence (AI)-Enhanced Medical Drones in the Healthcare Supply Chain (HSC) for Sustainability Development:

A Case Study. *Journal of Cleaner Production, 328,* Article ID: 129598. https://doi.org/10.1016/j.jclepro.2021.129598

Dubey, R., Gunasekaran, A., Bryde, D. J., Dwivedi, Y. K., & Papadopoulos, T. (2020). Blockchain Technology for Enhancing Swift-Trust, Collaboration and Resilience within a Humanitarian Supply Chain Setting. *International Journal of Production Research, 58,* 3381-3398. https://doi.org/10.1080/00207543.2020.1722860

Karuppiah, K., Sankaranarayanan, B., Ali, S. M., & Paul, S. K. (2021). Key Challenges to Sustainable Humanitarian Supply Chains: Lessons from the COVID-19 Pandemic. *Sustainability, 13,* Article 5850. https://doi.org/10.3390/su13115850

Kashav, V., & Garg, C. P. (2024). Fortifying Humanitarian Supply Chains: Evaluating Sustainability Enablers for Strengthened Resilience of Humanitarian Supply Chains during Calamities and Pandemics. *Journal of Humanitarian Logistics and Supply Chain Management.* https://doi.org/10.1108/jhlscm-04-2024-0050

Liu, M., Cao, J., & Zhang, D. (2020). Dynamic Adjustment Method for Optimizing Epidemic-Logistics Network Based on Data-Driven. Systems *Engineering-Theory & Practice, 40,* 437-448. (In Chinese) https://doi.org/10.12011/1000-6788-2018-1690-12

Longo, F., Mirabelli, G., Padovano, A., & Solina, V. (2023). The Digital Supply Chain Twin Paradigm for Enhancing Resilience and Sustainability against Covid-Like Crises. *Procedia Computer Science, 217,* 1940-1947. https://doi.org/10.1016/j.procs.2022.12.394

Najjar, M. S., Dahabiyeh, L., & Nawayseh, M. (2019). Share If You Care: The Impact of Information Sharing and Information Quality on Humanitarian Supply Chain Performance—A Social Capital Perspective. *Information Development, 35,* 467-481. https://doi.org/10.1177/0266666918755427

Patil, A., Shardeo, V., Dwivedi, A., Madaan, J., & Varma, N. (2021). Barriers to Sustainability in Humanitarian Medical Supply Chains. *Sustainable Production and Consumption, 27,* 1794-1807. https://doi.org/10.1016/j.spc.2021.04.022

Peng, L., Xu, H., Lu, J., Luo, J., & Zhan, H. (2022). An Integrated Approach with CLFPR-Based ANP and Fuzzy TOPSIS for Evaluating Business Performance of Rural Homestays: Study from China. *Sustainability, 15,* Article 538. https://doi.org/10.3390/su15010538

Rehman Khan, S. A., Yu, Z., Sarwat, S., Godil, D. I., Amin, S., & Shujaat, S. (2022). The Role of Block Chain Technology in Circular Economy Practices to Improve Organisational Performance. *International Journal of Logistics Research and Applications, 25,* 605-622. https://doi.org/10.1080/13675567.2021.1872512

Saputro, K. E. A., Hasim, Karlinasari, L., & Beik, I. S. (2023). Evaluation of Sustainable Rural Tourism Development with an Integrated Approach Using MDS and ANP Methods: Case Study in Ciamis, West Java, Indonesia. *Sustainability, 15,* Article 1835. https://doi.org/10.3390/su15031835

Tseng, M., Bui, T., Lim, M. K., & Lewi, S. (2021). A Cause and Effect Model for Digital Sustainable Supply Chain Competitiveness under Uncertainties: Enhancing Digital Platform. *Sustainability, 13,* Article 10150. https://doi.org/10.3390/su131810150

Van Wassenhove, L. N. (2006). Humanitarian Aid Logistics: Supply Chain Management in High Gear. *Journal of the Operational Research Society, 57,* 475-489. https://doi.org/10.1057/palgrave.jors.2602125

Woldt, J. J., Prasad, S., & Tata, J. (2019). Supply Chain Management, National Culture, and Refugee Network Performance. *Journal of Humanitarian Logistics and Supply Chain Management, 9,* 109-130. https://doi.org/10.1108/jhlscm-12-2018-0075

Zhao, M., & Liu, X. (2018). Development of Decision Support Tool for Optimizing Urban Emergency Rescue Facility Locations to Improve Humanitarian Logistics Management. *Safety Science, 102,* 110-117. https://doi.org/10.1016/j.ssci.2017.10.007

Zhou, X., Wang, L., Qin, J., Chai, J., & Gómez Muñoz, C. Q. (2019). Emergency Rescue Planning under Probabilistic Linguistic Information: An Integrated FTA-ANP Method. *International Journal of Disaster Risk Reduction, 37,* Article ID: 101170. https://doi.org/10.1016/j.ijdrr.2019.101170