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Causal Structure of Institutional Factors Influencing the Digitalization of the Humanitarian Supply Chain: A Thematic Analysis–DEMATEL Approach

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ABSTRACT

The purpose of this study is to identify and analyze the causal structure of institutional factors influencing the digitalization of the humanitarian supply chain. The research seeks to determine which institutional dimensions function as the primary drivers of digital transformation and which dimensions are more influence-receiving, in order to present a systematic depiction of the institutional mechanisms required to realize digital transformation in relief and rescue operations. In the first phase, to extract institutional factors, an integrative thematic analysis was conducted based on the literature and 12 semi-structured interviews with experts in crisis management and humanitarian relief. The output of this phase was the classification of factors into six main dimensions: public policymaking and governance regulations, leadership and change management, data management and information transparency, inter-organizational coordination and management, infrastructure and cybersecurity, and culture-building and future orientation. In the second phase, to analyze causal relationships and determine the intensity of influence of each dimension, the DEMATEL method was applied using the judgments of seven experts in the fields of digitalization and crisis management. The findings indicate that public policymaking and governance regulations constitute the most influential factor and the primary driver of digitalization. Leadership and change management play an intermediary driving role by transmitting macro-level policies to operational levels. In contrast, dimensions such as data management, inter-organizational coordination, cybersecurity, and culture-building are more influence-receiving, and their strengthening depends on policy and managerial domains. By presenting an institutional–causal framework, the present study demonstrates that the digitalization of the humanitarian supply chain is not merely a technological project, but rather a governance and change management issue. The main added value of this research lies in integrating in-depth qualitative analysis with quantitative causal modeling (DEMATEL) and providing a prioritized roadmap for policymakers and humanitarian managers, enabling them to design the path of digital transformation with a focus on the most critical institutional factors.

Keywords: Digitalization; humanitarian supply chain; institutional factors; crisis management; thematic analysis; DEMATEL.

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Introduction

Digital transformation has become a defining capability for contemporary supply chains, particularly under conditions of volatility, disruption, and interdependence. In networked supply chain environments, digital technologies can reconfigure coordination structures, expand visibility, and enable faster sensing and response, thereby strengthening resilience at both organizational and system levels {Tian, 2025 #341414}. In humanitarian contexts, where logistics must operate under extreme uncertainty, time pressure, and fragmented information, the promise of digitalization is especially consequential because it can improve the speed, fairness, and safety of relief flows while reducing operational friction {Khan, 2022 #341436}. At the same time, humanitarian supply chains are embedded in institutional and regulatory environments that shape what technologies can be adopted, how data can be governed, and which actors are authorized to coordinate action, meaning that "digitalization" cannot be understood as a purely technical upgrade but rather as a socio-institutional transformation of operating models and governance arrangements {Marić, 2021 #341400}.

The literature on humanitarian supply chain digitalization has expanded rapidly, reflecting both technological maturity and escalating disaster complexity. A growing body of research highlights how digital tools—ranging from real-time data capture to advanced analytics, IoT, and platform-based coordination—can reduce information asymmetry and improve end-to-end decision quality in disaster response {Yagci Sokat, 2016 #341441}. In parallel, empirical and conceptual work has positioned digitalization as a pathway to enhanced performance management in humanitarian operations, emphasizing the need to translate technology investments into measurable operational outcomes and accountability mechanisms {Jayadi, 2025 #341428}. However, evidence also suggests that digital transformation outcomes vary significantly across contexts, and that success depends not only on the availability of technology but also on organizational capabilities, inter-organizational alignment, and the broader governance environment within which humanitarian actors operate {Ülkü, 2024 #341439}. This variation implies that identifying institutional enablers and constraints is central for explaining why digital initiatives scale in some settings but stall in others.

A central driver of interest in humanitarian digitalization is the increasing relevance of data-driven approaches for preparedness, response, and recovery. Data-driven digital transformation has been associated with "antifragility" in humanitarian supply chains, whereby systems learn and improve under stress when they can generate, share, and exploit high-quality data {Bag, 2023 #341408}. Complementing this view, research has emphasized the role of information alignment and collaboration as mutually reinforcing conditions for agility, especially when multiple agencies must synchronize decisions and resource flows under severe constraints {Dubey, 2021 #341416}. Yet, humanitarian operations often face persistent gaps in standardized data collection, data sharing, and agency coordination, which limits the effectiveness of digital tools and undermines collective action {Shalash, 2022 #341432}. The institutional nature of these gaps is critical: data standards, interoperability rules, and coordination protocols are typically shaped through policy, governance, and cross-organizational agreements rather than by technology alone.

The ethical and legal dimensions of digital transformation further intensify the institutional challenge in humanitarian settings, where vulnerable populations are at heightened risk of harm from data misuse, surveillance, or exclusion. Analyses of artificial intelligence in humanitarian action highlight a duality of opportunity and risk, noting that algorithmic tools can enhance targeting and situational awareness while also generating bias, opacity,

and accountability deficits if not governed appropriately {Beduschi, 2022 #341411}. Related work has argued that AI adoption must be reconciled with humanitarian obligations, including principles of protection and duty of care, which requires governance mechanisms that can operationalize ethical commitments under real-world constraints {Trusilo, 2023 #341401}. In crisis contexts such as wartime or large-scale displacement, data governance must also address heightened vulnerability, necessitating principles and practices that go beyond generic “best practices” and explicitly protect at-risk communities in data lifecycles {Suchikova, 2025 #341412}. These concerns position institutional safeguards—laws, standards, oversight, and accountability—as necessary conditions for legitimate and sustainable digitalization.

Beyond governance, the enabling role of advanced technologies in humanitarian logistics is increasingly documented, but the pathway from technology potential to operational value remains mediated by institutional readiness. Reviews of Industry 4.0 technologies in humanitarian supply chains identify significant potential for sustainability and efficiency gains but also point to constraints related to infrastructure, capability, and inter-organizational integration {Ülkü, 2024 #341439}. At the operational level, evidence from country settings suggests that digitalization can improve logistical efficiency, yet it depends on stable infrastructure and supportive institutional arrangements to translate systems into performance improvements {Vhikai, 2024 #341418}. Technology-specific applications, such as 3D printing, illustrate similar dynamics: while decentralized production can enhance responsiveness, it also introduces governance questions about quality assurance, certification, and coordination across dispersed actors {Corsini, 2022 #341417}. In this sense, institutional factors can be conceptualized as upstream “conditions of possibility” that shape whether digital tools become scalable capabilities or remain isolated pilots.

The rapid diffusion of analytics, machine learning, and AI has also reshaped the frontier of humanitarian supply chain design and decision-making. Post-disaster supply chains are increasingly being modeled with machine learning and multi-criteria decision methods to improve allocation, routing, and prioritization under uncertainty, reinforcing the role of data infrastructures and governance as prerequisites for advanced analytics {Shakibaei, 2024 #341430}. Multiagent systems for resource distribution likewise show how algorithmic coordination can be enhanced through distributed decision architectures, but these approaches assume interoperable data, defined authority structures, and agreed operating rules among actors {Icarte-Ahumada, 2023 #341440}. From a capability perspective, the convergence of AI and big data is positioned as a resilience lever for humanitarian supply chains, but it is contingent on data availability, sharing norms, and institutional trust—conditions that are frequently fragile in crisis ecosystems {Ahatsi, 2024 #341431}. Accordingly, a key analytical problem is not whether advanced digital tools can work, but under what institutional configurations they can be adopted responsibly and operated effectively.

An additional mechanism through which institutional dynamics matter is collaboration across sectors and organizational boundaries. Public–private collaborations have been shown to materially influence humanitarian supply chain success when digital transformation is used to integrate competencies, accelerate decision cycles, and enhance coordination across partners {Akhtar, 2025 #341409}. Yet, collaboration is rarely frictionless: differences in mandates, accountability regimes, and information-sharing constraints can impede integration unless governance mechanisms create clarity on roles, incentives, and data stewardship. Blockchain-based initiatives have been examined as one route to enhancing swift trust, collaboration, and resilience, particularly by improving traceability and reducing opportunism in multi-actor relief networks {Dubey, 2020 #341415}. Evidence from humanitarian blockchain pilot projects suggests tangible benefits but also highlights implementation barriers rooted

in governance, stakeholder alignment, and regulatory constraints {Baharmand, 2021 #341424}. Studies emphasizing blockchain for information alignment and coordination similarly imply that the technology's value depends on cross-institutional agreement about standards, participation, and data control {Dubey, 2024 #341426}. These insights reinforce the premise that institutional design—not technology selection alone—determines whether digital innovations can be embedded into routine humanitarian operations.

Digital transformation research in broader supply chain contexts also offers theoretical lenses for institutional analysis. Work on digital supply chain transformation under "new norms" highlights the role of knowledge absorptive capacity and relationship quality in determining transformation outcomes, suggesting that organizations must be able to acquire, assimilate, and exploit digital knowledge while sustaining cooperative inter-organizational relationships {Al-Omoush, 2024 #341429}. Empirical studies on SMEs' willingness to adopt digital technologies likewise indicate that adoption decisions are shaped by multi-level drivers that include perceived benefits, capability constraints, and contextual pressures, emphasizing that institutional environments can either amplify or dampen adoption intent {Wu, 2024 #341442}. In humanitarian settings, where multiple organizations with heterogeneous capabilities must coordinate, these adoption dynamics become more complex because decisions are not purely firm-level but also network-level and governance-mediated.

A consistent theme across the humanitarian digitalization literature is the persistence of barriers that are fundamentally institutional in nature. Research has documented barriers to information and digital technology adoption such as lack of standards, limited data-sharing willingness, capability gaps, and governance fragmentation, indicating that interventions must address both technical and institutional constraints {Kabra, 2023 #341427}. IoT adoption studies in humanitarian logistics further show that barriers are interdependent and can form causal chains, where regulatory clarity, coordination capacity, and infrastructure readiness condition the feasibility of deployment and scaling {Rejeb, 2024 #341437}. The practical implication is that policymakers and humanitarian leaders need structured approaches for prioritizing institutional interventions, because attempting to address barriers in an arbitrary sequence can yield weak results when upstream constraints remain unresolved.

Given these interdependencies, methodological approaches capable of representing causal structures among institutional factors have become increasingly important. The DEMATEL technique has been widely used to model complex cause–effect relationships and to distinguish driving factors from dependent factors, making it suitable for prioritizing intervention levers in multi-factor systems {Si, 2018 #341433}. In humanitarian supply chain research, group-DEMATEL approaches have been applied to identify factors affecting blockchain use and to map influence structures among adoption determinants, highlighting the method's utility for disentangling structural relationships beyond simple ranking {Chen, 2023 #341402}. More broadly, improved DEMATEL variants that integrate subjective expert judgment with objective data have been proposed to enhance robustness and reduce bias, which is particularly relevant when institutional factors must be evaluated under uncertainty and limited quantitative evidence {Du, 2019 #341404}. DEMATEL is also increasingly combined with complementary structuring methods to generate comprehensive influence maps for complex socio-technical systems, which supports interpretive clarity for managerial decision-making {Hu, 2024 #341405}.

Despite the accumulation of findings, important gaps remain in synthesizing institutional factors into a coherent causal architecture specifically for humanitarian supply chain digitalization. While the literature offers insights on technology applications, ethical and legal risks, and coordination barriers, there is still limited empirical work that integrates qualitative discovery of context-specific institutional factors with quantitative causal modeling that can

inform prioritization and sequencing of interventions. Prior studies emphasize the role of organizational culture and analytics in building swift trust and collaborative performance, implying that cultural and relational institutions can shape digital outcomes, but they do not always specify how these factors interact causally with governance, leadership, and infrastructure dimensions in a unified model {Dubey, 2019 #341407}. Similarly, disaster management research that designs digital systems for earthquake management illustrates the relevance of institutional readiness and spatial–information infrastructures, yet it leaves open the question of which institutional dimensions function as root drivers in broader humanitarian digitalization programs {Sadidi, 2018 #341403}. In addition, the COVID-19 era amplified the urgency of responsible data governance, particularly under privacy regulations such as the GDPR, underscoring that data-driven humanitarian innovation must be aligned with legal regimes and institutional safeguards rather than pursued through ad hoc experimentation {Gazi, 2020 #341410}.

Furthermore, contemporary humanitarian digitalization is increasingly tied to localization and insider-led processes, which introduce additional institutional considerations about authority, legitimacy, and governance across global–local actor networks. Evidence from humanitarian protection contexts shows that digital technologies can support localization outcomes when processes are led by insiders and aligned with local institutional realities, indicating that governance arrangements determine whether technology empowers local actors or reinforces external control {Kaplan, 2025 #341419}. This perspective expands the institutional lens beyond formal regulation to include legitimacy, participation, and the social organization of decision rights in digital humanitarian systems. In parallel, sector-specific supply chain studies—such as pharmaceutical supply chain risk research and action research on collaborative knowledge creation—illustrate that digital transformation is enacted through multi-actor negotiation and learning, where governance, coordination, and leadership shape the translation of digital strategies into operational routines {Ciceri, 2025 #341423; Farinelli, 2023 #341434}. These insights suggest that humanitarian supply chain digitalization should be analyzed as a multi-actor institutional process rather than a single-organization technology program.

Another driver of institutional complexity is the growing role of emerging technologies such as AI and blockchain in humanitarian operations, which can alter power relations, accountability pathways, and risk profiles. Research on key drivers for AI incorporation in humanitarian supply chain management underscores that adoption is guided not only by technical feasibility but also by governance readiness, capability maturity, and the need for trustworthy decision systems {Karuppiah, 2025 #341421}. In government-linked supply chains, incentive mechanisms for data governance have been designed using blockchain architectures, emphasizing that governance instruments—such as incentives, compliance structures, and shared rules—can be engineered to support data stewardship and institutional alignment {Wei, 2023 #341438}. These developments imply that institutional factors relevant to humanitarian digitalization include not only rules and coordination mechanisms, but also incentive structures and capability-building interventions that enable sustained use of digital systems.

In light of these considerations, a rigorous institutional analysis must account for the causal hierarchy among governance regulations, leadership and change management, data governance, inter-organizational coordination, infrastructure and cybersecurity, and culture-building for digital readiness. The humanitarian supply chain is characterized by temporary networks, high turnover of actors, and shifting mandates across crises, which can destabilize institutional arrangements unless standardized process models and shared operational languages are established {Saïah, 2023 #341422}. At the same time, the field increasingly recognizes that technology-enabled coordination requires formalized methods for real-time data capture and verification to support decision-making

under uncertainty, which again depends on institutional commitments to interoperability and data stewardship {Yagci Sokat, 2016 #341441}. The resulting challenge for both research and practice is to determine which institutional dimensions constitute primary “drivers” that activate progress across the system and which dimensions are predominantly “dependent,” improving mainly as a consequence of upstream governance and leadership decisions.

Accordingly, the present study responds to the need for an integrated and prioritized understanding of institutional determinants of humanitarian supply chain digitalization by combining qualitative thematic analysis with quantitative causal modeling through DEMATEL, building on established methodological foundations for mapping influence structures in complex systems {Si, 2018 #341433}. It also aligns with recent calls to evaluate digital transformation pathways in humanitarian contexts through rigorous evidence and structured performance perspectives, rather than through isolated technology narratives {Jayadi, 2025 #341428}. By drawing on contemporary scholarship that highlights resilience imperatives, institutional and ethical constraints, and the growing role of AI, analytics, and blockchain, the study seeks to provide a systematic causal map that can guide policymakers and humanitarian managers in sequencing interventions and allocating attention to the most leverage-bearing institutional drivers {Tian, 2025 #341414; Beduschi, 2022 #341411; Dubey, 2024 #341426}.

The aim of this study is to identify the institutional factors influencing the digitalization of the humanitarian supply chain and to model their cause–effect relationships in order to determine the primary driving dimensions and the most influence-receiving dimensions within an integrated causal framework.

Methods and Materials

This study was conducted using a mixed qualitative–quantitative approach implemented in two complementary phases. In the first phase, thematic analysis was employed to extract and identify institutional factors related to the digitalization of the humanitarian supply chain. In the second phase, the DEMATEL method was used to explain the causal relationships and patterns of influence among these factors. This research design enables the simultaneous, data-driven identification of key factors and the structural modeling of their interrelationships.

Phase One: Thematic Analysis

Data Sources

To identify institutional factors, two complementary categories of data were collected.

Semi-structured interviews were conducted with experts, including operations managers in humanitarian relief organizations, information technology specialists in NGOs, and experts in policymaking and digital transformation.

The interviews continued until theoretical saturation was achieved (a total of 12 interviews were conducted).

In addition, document and text analysis was carried out, including scientific articles, international standards, relevant regulations, and official reports related to the digitalization of the humanitarian supply chain. The integration of these two data sources enabled data triangulation, thereby enhancing the credibility of the extracted themes.

Coding Procedures

The thematic analysis was conducted based on the six-phase framework proposed by Braun and Clarke (2006).

Data familiarization: Transcription of interviews, repeated reading, and recording of initial notes.

Initial coding: Identification of statements related to institutional pressures, structural barriers, digital capacity, and legal requirements.

Searching for themes: Grouping similar codes into preliminary themes.

Reviewing themes: Refinement, merging, or elimination of themes based on internal coherence and consistency with the data.

Defining and naming themes: Clarification of the content of each theme and formulation of operational definitions.

Final extraction of factors: Converting the main themes into foundational institutional factors for entry into the DEMATEL modeling stage.

To enhance reliability, the coding process was carried out by two independent coders, and inter-coder agreement was assessed using Cohen's kappa coefficient (values above 0.75 were considered acceptable).

DEMATEL Technique

The DEMATEL method can effectively analyze the degree of direct influence and causal relationships among different factors and represent the direct effects between factors in the form of a matrix. It can also be used to identify key factors and determine indicator weights.

Steps of the DEMATEL Technique

Step One: Construction of the Direct-Relation Matrix

To construct the direct-relation matrix, the influence of one factor on another is evaluated by experts based on a predefined scale. The degree of influence between two factors ranges from 0 to 4.

Table 1. Linguistic Variables in the DEMATEL Method

Linguistic Variable	Numerical Scale
No influence	0
Low influence	1
Moderate influence	2
High influence	3
Very high influence	4

Step Two: Normalization of the Direct-Relation Matrix

The normalization of the direct-relation matrix is performed using the following formula, which divides the direct-relation matrix (D) by the maximum row sum or column sum.

$$N = D.\frac{1}{\max\left(\max\sum_{j=1}^{n} D_{ij}, \max\sum_{i=1}^{n} D_{ij}\right)}$$

Step Three: Calculation of the Total-Relation Matrix

The total-relation matrix includes both direct and indirect effects among all factors. This matrix is calculated based on the formulation proposed by Hu using the following equation.

$$T = \lim_{k\to\infty}\left(N + N^2 + N^3 + \ldots + N^n\right) = N\left(I - N\right)^{-1}$$

Step Four: Calculation of Prominence and Relation Values

If R and C denote the sums of rows and columns of the total-relation matrix T, respectively, they are calculated using the following formulas.

$$R_i = \sum_{j=1}^{n} t_{ij}, (1, 2, 3, \ldots, n)$$

$$C_i = \sum_{j=1}^{n} t_{ji}, (1, 2, 3, \ldots, n)$$

Step Five: Calculation of the Final Reachability Matrix

To calculate the final reachability matrix (K), the total-relation matrix is first added to the identity matrix (I).

Then, using a threshold value, the new matrix (H) is converted into a binary matrix (final reachability matrix), where K = T indicates that there is an interaction between factor fi and factor fj. Otherwise, K = 0 indicates that there is no interaction between factor fi and factor fj (Hu et al., 2024). The threshold value λ is introduced to eliminate redundant information from matrix T by filtering out indicators with low degrees of influence (Du & Zhou, 2019). In the literature, λ values are typically selected based on expert judgment, which is less objective; however, calculating the mean plus a proportion of the standard deviation based on the statistical distribution can reduce subjectivity (Hu et al., 2024). In this study, the mean and half of the standard deviation were used.

$$\lambda = \mu + 0.5\sigma$$

$$K_{ij} = T,\ f_i h_{ij} > \lambda, (i,\ j = 1, 2, 3, ..., n)$$

$$K_{ij} = 0,\ f_i h_{ij} < \lambda, (i,\ j = 1, 2, 3, ..., n)$$

Step Six: Drawing the Causal Relationship Diagram

This step involves plotting the causal relationship map to visualize the institutional influence structure.

Data Quality Assurance

Content validity was confirmed through expert judgment and questionnaire review.

The reliability of expert judgments was assessed by examining standard deviations and consistency ratios.

The credibility of the integrated results was strengthened using triangulation methods (sources, instruments, and analysts).

Findings and Results

In this study, an integrative thematic analysis was conducted based on two data sources, including official documents related to digital transformation policies and semi-structured interviews with experts in the humanitarian supply chain and digital transformation. The analytical process was carried out in three main steps:

First, initial codes were extracted from documents;

Second, initial codes were analyzed from interviews;

Third, the two sets of codes were compared and integrated to form the final themes.

To ensure conceptual coherence, overlapping codes were consolidated as the core elements of the themes, while interview-specific codes were used as complementary and enriching elements.

Description of Final Themes and Key Messages

1) Inter-organizational Coordination and Management

Studies indicate that the absence of formal coordination mechanisms leads to parallel activities, task overlap, and resource waste among involved institutions. Clarifying roles, establishing a shared language, and defining a coordinating authority are among the main prerequisites for enhancing the efficiency of digital processes at the macro level.

Key message: The existence of a clear and national-level mechanism for coordinating institutions is an effective and essential factor in ensuring coherence and efficiency in the digital transformation process.

Table 2. Integration of Codes Extracted from Documents and Interviews for the Theme of Inter-organizational Coordination and Management

Final Theme	Code from Documents	Source	Code from Interviews	Quotation	Type of Integration
Inter-organizational coordination and management	Inter-institutional coordination, data exchange standardization	Dubey et al. (2024); Rejeb et al. (2024); Sadidi et al. (2018)	Identification of all organizations	"The problem is that first we do not even know which organizations are involved; this map must be clearly identified."	Overlapping + Complementary
			Proper task allocation	"When everyone knows their exact role, half of the problems are solved."	
			Appointment of a coordinator	"We need a single institution to say who should do what, rather than everyone acting separately."	
			Formation of a coordination leadership team	"If there is a joint coordination team among organizations, the processes become much smoother."	

2) Policymaking and Governance Regulations

The findings indicate that existing regulations are often outdated, unclear, or lack practical effectiveness in the digital domain. Timely revision of regulations, simplification of legal provisions, and the establishment of supportive frameworks for data create conditions for reducing ambiguity and enhancing implementability.

Key message: The existence of updated, understandable, and enforceable regulations is essential and acts as an influential factor in ensuring the sustainability and predictability of digital transformation.

Table 3. Integration of Codes Extracted from Documents and Interviews for the Theme of Policymaking and Governance Regulations

Final Theme	Code from Documents	Source	Code from Interviews	Quotation	Type of Integration
Policymaking and governance regulations	Addressing legal challenges, regulatory revision	Baharmand et al. (2021); Beduschi (2022); Rejeb et al. (2024); Trusilo and Danks (2023)	Principles of legal review	"First, we need to properly review the existing laws and see what we actually have."	Overlapping
			Law update process	"Outdated laws must be updated faster, especially in the digital field."	
			Strict enforcement of laws	"We have laws, but enforcement is not taken seriously; this causes disorder."	
			Approval of understandable laws	"Laws should not be complex; all organizations must easily understand them."	
			Legal protection of data and privacy	"Without strong laws on data and privacy, no one will share information with confidence."	

3) Data Management and Information Transparency

Studies show that data flows without clear pathways, standardized exchange mechanisms, and traceability constitute one of the main challenges in digital systems. Data transparency and standardization strengthen institutional trust and improve the quality of decision-making.

Key message: Establishing a national data architecture and transparency mechanisms is an essential factor for improving decision-making quality and increasing institutional trust.

Table 4. Integration of Codes Extracted from Documents and Interviews for the Theme of Data Management and Information Transparency

Final Theme	Code from Documents	Code from Interviews	Quotation	Type of Integration
Data management and information transparency	Defined data pathways		"It must be clear where data come from and where they go; currently, the pathways are ambiguous."	Overlapping + Complementary
	Information traceability		"Sometimes we cannot track what has happened to the data; it must be traceable."	
	Distribution transparency		"People and organizations should know how supplies are distributed; this transparency is very important."	
	Data sharing		"Organizations tend to keep information to themselves; there should be a mechanism for easier sharing."	
	Integrated information dissemination		"Information dissemination should be integrated, not handled separately by each organization."	

4) Leadership and Change Management

The findings show that transformational leadership is not limited to technological vision but rather consists of a combination of managerial skills, digital competencies, support for change, and the ability to mobilize people. Informed and capable leaders can reduce resistance and guide the transformation process.

Key message: Developing and selecting managers with both digital and managerial competencies is a necessary condition for the successful implementation of digital transformation programs.

Table 5. Integration of Codes Extracted from Documents and Interviews for the Theme of Leadership and Change Management

Final Theme	Code from Documents	Source	Code from Interviews	Quotation	Type of Integration
Leadership and change management	—	—	Selection of knowledgeable managers	"A manager who does not understand technology cannot advance a digital project."	Emergent
			Selection of up-to-date managers	"A manager must be up to date, not make decisions based on outdated methods."	
			Selection of change-supportive managers	"If the manager does not believe in transformation, others will not take it seriously either."	
			Formation of a digital transformation leadership team	"A dedicated digital transformation team is needed to follow up the work."	
			Charismatic leadership	"A strong leader who can bring others along has a significant impact."	
			Training managers for digital transformation	"Managers must be trained; transformation does not occur without training."	

5) Infrastructure and Cybersecurity

Studies indicate that unstable infrastructure, limited access, and security vulnerabilities are major barriers to the successful implementation of emerging technologies. Strengthening communication infrastructure, technical standardization, and cybersecurity resilience provides a foundation for sustainable digital services.

Key message: Enhancing infrastructure and cybersecurity resilience is a critical and influential factor for the continuity and trustworthiness of digital services.

Table 6. Integration of Codes Extracted from Documents and Interviews for the Theme of Infrastructure and Cybersecurity

Final Theme	Code from Documents	Source	Code from Interviews	Quotation	Type of Integration
Infrastructure and cybersecurity	Stable internet infrastructure, cybersecurity	Vhikai et al. (2024); Corsini et al. (2022); Wang et al. (2024); Dinh and O'Leary (2024)	Development of stable and secure internet infrastructure	"Without stable internet, no digital system can function properly."	Overlapping + Complementary
			Strong cyberspace	"Our cyberspace must be strengthened; vulnerabilities are currently high."	
			Data exchange standardization	"Without shared standards, data cannot be properly exchanged among organizations."	
			Improved cybersecurity	"Security must be high, especially when sensitive public data are involved."	
			Open internet access	"Freer and faster internet access is truly vital during crises."	

6) Culture-building and Future Orientation

The findings show that technology adoption is not possible without cultural change, continuous training, and the articulation of a credible future vision. Awareness-raising, empowerment of employees, and creating a clear and accessible image of the digital future reduce resistance and enhance stakeholder engagement.

Key message: Promoting digital culture and providing a clear vision accompanied by continuous training is a key factor in increasing acceptance and participation among stakeholders.

Table 7. Integration of Codes Extracted from Documents and Interviews for the Theme of Culture-building and Future Orientation

Final Theme	Code from Documents	Source	Code from Interviews	Quotation	Type of Integration
Culture-building and future orientation	Foresight, necessity of cultural change	Kabra et al. (2023); Dubey et al. (2022); Negi (2024)	Willingness for change	"When the will for transformation does not emerge at the policymaking level, digital tools practically fail to deliver results."	Overlapping + Complementary
			Empowering individuals to accept change	"We must prepare the workforce and even society; change cannot be accepted overnight."	
			Articulating a clear future vision	"When the future is shown clearly, resistance decreases."	
			Articulating an accessible future	"The future must be tangible; if it seems too distant, no one will believe in it."	

Determining the Cause–Effect Relationships of Institutional Digitalization Factors

In this study, to simplify and facilitate presentation, each institutional factor examined is represented by an abbreviated code from D1 to D6. The corresponding meaning of each code is provided in Table 8.

Table 8. Abbreviated Codes for the Institutional Factors

Institutional factors examined	Abbreviated code
Inter-organizational coordination and management	D1
Policymaking and governance regulations	D2
Data management and information transparency	D3
Leadership and change management	D4
Infrastructure and cybersecurity	D5
Culture-building and future orientation	D6

To complete the direct-effects matrix, the opinions of seven senior experts were collected. These experts were selected based on three criteria:

1. managerial experience in humanitarian relief organizations or governmental institutions in the field of crisis management,
2. experience participating in digital projects or systems in the humanitarian relief domain,
3. familiarity with institutional processes and relevant regulations. The participation of this group enabled a valid and precise assessment of institutional relationships and the determination of the intensity of influence among factors.

First, the direct-relation matrix was constructed based on expert judgments to specify the intensity of the influence of each factor on other factors on a 0–4 scale. This matrix indicates that factor D2 has the highest direct influence, suggesting that the matrix is convergent. Then, for standardization purposes, the normalized matrix was generated using Equation (1).

Table 9. Initial Direct-Relation Matrix

	D1	D2	D3	D4	D5	D6	ΣD
D1	0.0	1.3	2.9	2.7	1.6	2.3	10.7
D2	3.1	0.0	3.3	3.3	3.4	3.0	16.1
D3	3.0	2.0	0.0	1.9	1.6	2.6	11.0
D4	2.9	2.1	2.9	0.0	3.0	3.1	14.0
D5	1.9	1.0	3.3	1.7	0.0	1.4	9.3
D6	2.4	1.7	2.6	2.3	1.4	0.0	10.4
ΣD	13.3	8.1	14.9	11.9	11.0	12.4	

Table 10. Normalized Direct-Relation Matrix (N)

N	D1	D2	D3	D4	D5	D6
D1	0.000	0.080	0.177	0.168	0.097	0.142
D2	0.195	0.000	0.204	0.204	0.212	0.186
D3	0.186	0.124	0.000	0.115	0.097	0.159
D4	0.177	0.133	0.177	0.000	0.186	0.195
D5	0.115	0.062	0.204	0.106	0.000	0.088
D6	0.150	0.106	0.159	0.142	0.088	0.000

$$N_{32} = \frac{2.0}{16.1} = 0.124$$

After normalizing the direct-relation matrix, the total-relation matrix was computed using Equation (2). This matrix incorporates indirect effects in addition to direct effects among factors and provides a comprehensive representation of the system's causal structure.

Table 11. Total-Relation Matrix (T)

T	D1	D2	D3	D4	D5	D6	R
D1	0.3484	0.3041	0.5285	0.4530	0.3715	0.4527	2.4582
D2	0.6602	0.3249	0.7135	0.6132	0.5843	0.6245	3.5207
D3	0.5145	0.3429	0.3883	0.4233	0.3786	0.4736	2.5213
D4	0.5848	0.4007	0.6258	0.3872	0.5114	0.5723	3.0823
D5	0.4048	0.2578	0.4991	0.3615	0.2422	0.3650	2.1305
D6	0.4736	0.3206	0.5092	0.4291	0.3606	0.3232	2.4163
C	2.9863	1.9510	3.2644	2.6674	2.4488	2.8113	

To compute the influence and dependence indices, calculations were performed based on the total-relation matrix using Equations (3) and (4). Then, (R + C) was used to derive the overall prominence of each factor, and (R − C) was used to identify whether each factor plays a causal (net influencing) or effect (net influenced) role. The final values of these indices for the institutional factors are reported in Table 12.

Table 12. Influence and Dependence Indices

	R	C	R + C	R − C
D1	2.4582	2.9863	5.4444	-0.5281
D2	3.5207	1.9510	5.4717	1.5696
D3	2.5213	3.2644	5.7857	-0.7430
D4	3.0823	2.6674	5.7497	0.4149
D5	2.1305	2.4488	4.5792	-0.3183
D6	2.4163	2.8113	5.2276	-0.3950

After computing the total-relation matrix, the indices of influence (R), dependence (C), total prominence (R + C), and cause–effect role (R − C) were extracted for each institutional dimension. The results show that policymaking and governance regulations have the highest R − C value and function as a causal dimension and the primary driving force in the system. Leadership and change management also have a positive but smaller R − C value, indicating a causal and mediating role.

In contrast, the dimensions of inter-organizational coordination and management, data management and information transparency, infrastructure and cybersecurity, and culture-building and future orientation have negative R − C values and are therefore classified as effect dimensions.

Moreover, based on the R + C index, data management and information transparency and leadership and change management exhibit the highest overall prominence.

Next, the cause–effect diagram was drawn using the total-relation matrix after applying the threshold. The threshold value (λ) was defined as follows:

$$\lambda = 0.448 + 0.5(0.117) = 0.506$$

Table 13. Total-Relation Matrix After Applying the Threshold

	D1	D2	D3	D4	D5	D6
D1	0	0	0.5285	0	0	0
D2	0.6602	0	0.7135	0.6132	0.5843	0.6245
D3	0.514503	0	0	0	0	0

D4	0.5848	0	0.6258	0	0.5114	0.5723
D5	0	0	0	0	0	0
D6	0	0	0.5092	0	0	0

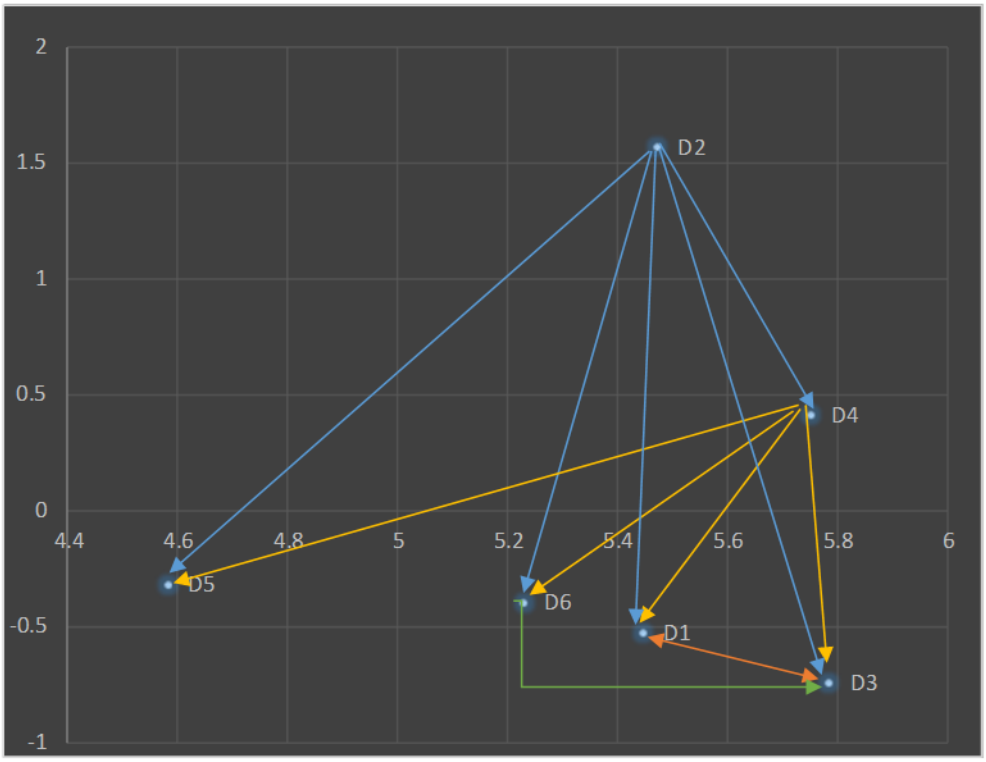

Figure 1. Cause–Effect Diagram of Institutional Factors Influencing Digitalization

By applying the threshold to the total-relation matrix, only links whose influence intensity exceeded the specified value were retained. Accordingly, the post-threshold total-relation matrix indicates which relationships in the causal network are meaningful and constitute genuine influential links. Based on this matrix, the highest density of relationships pertains to the dimensions of policymaking and governance regulations and leadership and change management, which continue to function as guiding elements. In contrast, some dimensions, such as infrastructure and cybersecurity, exhibit no meaningful relationships after thresholding and primarily operate as responding variables. The schematic derived from this matrix visually represents the network structure and shows how the primary pathways of influence transmission branch from policymaking toward other dimensions, while secondary influence flows are directed predominantly toward change management, data management, and culture-building. This visualization highlights the final pattern of institutional interactions after statistical filtering of salient relationships and clarifies the actual structure of influence and dependence among the dimensions.

Discussion and Conclusion

The findings provide a coherent institutional–causal explanation for why digitalization in humanitarian supply chains progresses unevenly across contexts and why technology-centric interventions often underperform when governance and managerial foundations are weak. The DEMATEL results indicate that policymaking and governance regulations (D2) hold the highest positive net causal role (R–C) and therefore function as the primary driver of the institutional system. This outcome implies that digitalization in humanitarian logistics is first and

foremost a governance problem: without updated, enforceable, and operationally interpretable rules for data stewardship, inter-agency mandates, accountability, and cross-sector collaboration, the adoption of digital technologies remains episodic, fragmented, and difficult to scale. This interpretation aligns with scholarship emphasizing that humanitarian digital initiatives must be embedded in institutional and regulatory architectures to remain legitimate and sustainable {Beduschi, 2022 #341411}, and with ethical analyses arguing that AI-enabled humanitarian action requires clear obligation structures, accountability mechanisms, and governance safeguards that translate normative commitments into operational constraints {Trusilo, 2023 #341401}. In practical terms, the prominence of D2 underscores that legal clarity and policy coherence shape the feasibility of data sharing, platform interoperability, and digital coordination during crises, which is consistent with evidence that privacy and regulatory frameworks can significantly constrain crisis analytics and humanitarian data practices when not reconciled with operational needs {Gazi, 2020 #341410}. The centrality of governance is also consistent with the localization perspective showing that digital humanitarian protection outcomes depend on decision rights, legitimacy, and institutional alignment with local realities rather than on technology availability alone {Kaplan, 2025 #341419}.

A second major result is the causal and mediating role of leadership and change management (D4). Although D4's net causal effect is smaller than D2, its positive R–C value indicates that leadership operates as a transmission mechanism through which macro-level policies become implementable routines, resourced programs, and coordinated inter-organizational practices. This is consistent with research showing that digital transformation outcomes depend on managerial capacities to mobilize partners, sustain collaboration, and convert information alignment into operational agility in humanitarian supply chains {Dubey, 2021 #341416}. The leadership finding also resonates with broader digital supply chain transformation studies demonstrating that transformation value depends on capabilities that enable organizations to absorb, integrate, and deploy knowledge across relationships and operational processes {Al-Omoush, 2024 #341429}. From this perspective, governance (D2) creates the "rules of the game," but leadership (D4) determines whether those rules become executable change portfolios and whether the organization and its partners can navigate resistance, ambiguity, and resource constraints. This mediating logic is consistent with action research evidence that guiding digital transformation in multi-actor supply chains requires deliberate leadership to orchestrate collaborative knowledge creation and to institutionalize new practices {Farinelli, 2023 #341434}. It also aligns with performance management arguments suggesting that digitalization gains traction when leaders build measurement architectures and accountability routines that connect technology use to operational outcomes {Jayadi, 2025 #341428}.

In contrast, the study identifies inter-organizational coordination and management (D1), data management and information transparency (D3), infrastructure and cybersecurity (D5), and culture-building and future orientation (D6) as predominantly influence-receiving dimensions (negative R–C values). This pattern is theoretically meaningful because it indicates that these dimensions improve primarily as downstream effects of policy and leadership interventions rather than as independent starting points. For example, coordination capacity (D1) depends on clarified mandates, standardized protocols, and formal mechanisms for aligning agencies—conditions typically created through governance reforms (D2) and sustained through leadership (D4). This inference is supported by evidence that information alignment and coordination in humanitarian supply chains are strengthened when institutional arrangements enable collaboration and shared standards, and when technologies such as blockchain are embedded into agreed governance structures rather than deployed as isolated tools {Dubey, 2024 #341426}. Similarly, findings on the need for standardized methods of data collection and sharing, along with

improved agency coordination, indicate that coordination deficits are not merely operational failures but are rooted in institutional fragmentation and the absence of shared process models {Shalash, 2022 #341432}. The role of standardized humanitarian process models further supports the conclusion that coordination (D1) strengthens when governance and inter-agency agreements codify shared operating procedures and responsibilities across crisis phases {Saïah, 2023 #341422}.

The results also show that data management and information transparency (D3) has among the highest total prominence (R+C), despite being influence-receiving. This implies that D3 is highly connected within the system and is central to overall performance, even if it is not the primary causal driver. This is consistent with the view that data-driven digital transformation can enable antifragility and resilience, but only when data quality, accessibility, and governance arrangements are institutionalized across actors {Bag, 2023 #341408}. It also aligns with evidence that real-time data capture is foundational to effective disaster response logistics and that the operational value of data is realized through institutional commitments to standardization, verification, and integration across agencies {Yagci Sokat, 2016 #341441}. The prominence of D3 also coheres with the increasing integration of machine learning and decision-support systems in post-disaster humanitarian supply chains, where advanced analytics require reliable data architectures, traceability, and accountable data pipelines {Shakibaei, 2024 #341430}. Furthermore, the convergence of AI and big data for humanitarian supply chain resilience emphasizes that the resilience value of analytics depends on institutional trust and data governance capacity, echoing why D3 becomes pivotal yet structurally dependent {Ahatsi, 2024 #341431}. The study's finding that D3 is influence-receiving also aligns with governance-driven data-protection arguments, which suggest that without clear legal protections and operational policies for data stewardship, transparency and sharing mechanisms remain weak regardless of technology investments {Suchikova, 2025 #341412}.

The downstream positioning of infrastructure and cybersecurity (D5) and the post-threshold network result that D5 lacks salient outgoing relationships after thresholding provide a nuanced managerial implication. While infrastructure and cybersecurity are widely recognized as critical enablers, in the present causal structure they appear primarily as "response variables" that are strengthened once governance priorities, funding allocations, technical standards, and leadership mandates are established. This does not imply that infrastructure is unimportant; rather, it indicates that infrastructure readiness is often an outcome of strategic choices and policy frameworks that determine investment, standardization, and acceptable risk thresholds. This interpretation is consistent with evidence that digitalization can improve humanitarian logistical efficiency in real-world settings but is strongly conditioned by infrastructure stability and institutional support for operational continuity {Vhikai, 2024 #341418}. It also aligns with reviews of Industry 4.0 technologies in humanitarian supply chains that highlight infrastructural and capability constraints as systemic bottlenecks but implicitly situate their resolution within broader institutional programs and cross-organizational planning {Ülkü, 2024 #341439}. Technology-specific innovations such as 3D printing illustrate the same structural logic: technical feasibility and performance gains are contingent on governance arrangements for quality assurance, certification, and coordinated deployment, which are typically policy- and leadership-driven rather than purely operational choices {Corsini, 2022 #341417}.

The influence-receiving role of culture-building and future orientation (D6) also aligns with established evidence that organizational culture and trust dynamics complement analytics and collaboration in humanitarian supply chain performance. Prior work demonstrates that big data analytics capabilities interact with organizational culture to support swift trust and collaborative performance in humanitarian networks {Dubey, 2019 #341407}. The present

findings suggest that culture-building initiatives become more effective when governance and leadership establish consistent narratives, incentives, and learning systems that make digital practices normal, legitimate, and supported. This is consistent with barrier analyses identifying cultural resistance, capability gaps, and weak information norms as key impediments to adopting digital technologies in humanitarian supply chains {Kabra, 2023 #341427}. The study's causal ordering implies that culture change is less likely to be sustained when policy signals are ambiguous or when leadership does not institutionalize training, accountability, and cross-agency learning routines.

A further contribution of the study is its prioritization logic for addressing adoption barriers that are known to be interdependent. Research using ISM-DEMATEL to analyze barriers to IoT adoption in humanitarian logistics emphasizes that barriers form structured hierarchies, where upstream conditions—often institutional—shape downstream readiness and diffusion dynamics {Rejeb, 2024 #341437}. The current study extends this insight by demonstrating an institutional causal backbone in which policymaking/regulation (D2) and leadership/change management (D4) operate as core drivers that shape data governance (D3), coordination (D1), infrastructure and cybersecurity (D5), and culture-building (D6). This causal backbone helps reconcile why technically promising solutions such as blockchain can produce uneven outcomes: while blockchain can enhance trust, traceability, and collaboration, successful deployment depends on alignment among actors and on governance structures that specify participation rules, compliance expectations, and data stewardship responsibilities {Dubey, 2020 #341415}. Evidence from humanitarian blockchain pilots similarly indicates that implementation success depends on stakeholder alignment, policy support, and the institutional context of adoption—conditions that map closely onto D2 and D4 in the present model {Baharmand, 2021 #341424}. Complementary studies that model blockchain adoption determinants in humanitarian supply chains through group-DEMATEL further reinforce that the adoption environment is structured by interacting factors rather than single-variable "drivers," supporting the value of causal modeling for sequencing interventions {Chen, 2023 #341402}.

The results also speak to the expanding role of AI in humanitarian supply chain management and the institutional prerequisites for responsible scaling. Studies identifying key drivers for AI incorporation emphasize the need for governance readiness, capability maturity, and clarity in decision-making accountability when AI is introduced into humanitarian operations {Karuppiah, 2025 #341421}. The present findings position governance (D2) and leadership (D4) as the causal levers that can establish those prerequisites, while data governance (D3) becomes a highly prominent dependent dimension that mediates practical AI deployment quality. This interpretation aligns with ethical and legal scholarship cautioning that AI's benefits in humanitarian action are inseparable from risk management, accountability, and rights protection structures {Beduschi, 2022 #341411; Trusilo, 2023 #341401}. It also complements work on government incentive mechanisms for data governance, which demonstrates that institutional instruments—such as incentives, compliance architectures, and rule systems—can be designed to steer data practices, implying that policy design can directly condition downstream transparency and sharing behavior {Wei, 2023 #341438}.

Finally, the study's results reinforce the broader claim that digital transformation contributes to resilience when it is implemented as an integrated institutional program rather than as a portfolio of isolated technologies. Digital transformation and resilience research in supply chain networks emphasizes that resilience outcomes emerge from network-level reconfiguration of information flows and coordination patterns rather than from single-firm optimization {Tian, 2025 #341414}. In humanitarian contexts, the pursuit of "fast, fair, and safe" logistics likewise depends on

system-level institutional alignment that supports technology-enabled coordination and trusted information exchange {Khan, 2022 #341436}. The present model operationalizes this insight by revealing which institutional dimensions act as root drivers and which operate as downstream capacity areas. It also complements systematic review evidence on the emergent role of digital technologies in humanitarian supply chains, which suggests that research and practice must move beyond enumerating technologies toward understanding governance, collaboration, and capability dynamics that determine digital transformation trajectories {Marić, 2021 #341400}. Viewed together, the findings provide a structured explanation for the observed empirical variability in digital adoption and performance across humanitarian operations, while offering a practical prioritization map that emphasizes governance reform and leadership capability-building as the first-order levers for accelerating digitalization.

Limitations. The study relies on expert judgment to populate the DEMATEL matrices, and although the experts were selected based on relevant experience, the causal estimates may reflect contextual interpretations and subjective assessments rather than fully objective causal effects. The sample size for interviews and expert panels was appropriate for qualitative saturation and structured judgment elicitation, but the findings may not generalize to all humanitarian ecosystems, especially those with substantially different governance models, technology infrastructures, or donor coordination regimes. In addition, the cross-sectional nature of the data limits the ability to observe how institutional roles and causal strengths evolve over time across phases of digital transformation.

Suggestions for future research. Future studies could validate the proposed causal structure using longitudinal designs that track institutional reforms, digital capability development, and operational performance across multiple crisis events. Comparative multi-country research could examine whether the primacy of governance and leadership persists under different regulatory environments, coordination architectures, and levels of digital maturity. Mixed-method studies integrating DEMATEL with structural equation modeling or system dynamics could further quantify mediation pathways, test alternative causal configurations, and explore how feedback loops emerge as digitalization scales.

Suggestions for practice. Policymakers and humanitarian leaders should prioritize governance reforms that clarify data stewardship, interoperability requirements, accountability, and cross-agency mandates before investing heavily in specific technologies. Leadership development programs focused on digital change management should be institutionalized to ensure that policies translate into executable implementation roadmaps, aligned incentives, and sustained stakeholder engagement. Operational teams should treat data governance, coordination protocols, and cultural readiness as structured workstreams that follow from governance and leadership decisions, with explicit sequencing, resourcing, and performance monitoring to ensure durable digitalization outcomes.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adheried in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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