

Prioritizing and Mapping Drivers of Digital Transformation Toward Industry 5.0 in Humanitarian Logistics

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Abstract

It has now become almost necessary to adopt digital transformation in humanitarian logistics with regard to disaster responses becoming more prominent and complex. There still lacks an understanding of the important factors involved in ensuring the implementation of Industry 5.0 among these areas. The main objective of this paper is to pinpoint as well as assess the core elements needed for Industry 5.0-based digital transformation of humanitarian logistics processes. A total of twenty experts representing various NGOs globally, United Nations bodies, government disaster management units, and humanitarian technology solution companies participated in the analysis. By using a set of properly identified factors and carrying out Best-Worst Method (BWM) analysis for importance evaluation and Decision-Making Trial and Evaluation Laboratory Method (DEMATEL) to identify interactions among these factors, it was found that factors with highest influencer scores are strong analytical and data-driven decision-making capacities, committed leadership and donor support, effective information sharing across agencies, robust security and privacy practices, and a workforce capable of adopting new technologies. The causal network moreover emphasizes that analytical ability enhancement and interoperability of data among different organizations offer the utmost potential for facilitating digital transformation within the humanitarian sector. Lastly, this research offers an expert system Critical success factors (CSFs) model designed for humanitarian logistics under Industry 5.0 as well as an

analytical BWM/DEMATEL solution including with proper recommendations for designing human-centric secure, and resilient humanitarian supply chain strategies.

Keywords

Humanitarian logistics, Industry 5.0, Digital transformation, BWM, DEMATEL.

1. Introduction

The humanitarian logistics sector has been one of the most unstable environments in recent years with all the compounding factors of the climate-induced disasters, long-running geopolitical conflicts, and worldwide supply chain disruptions. Humanitarian operations operate at a level of extreme resource constraint, uncertainty, and ethical urgency to suffer alleviation compared to commercial operations, which are optimized to be cost and speed sensitive (Besiou & Van Wassenhove, 2020). With the intensification of the operational needs, the industry is being strained to implement digital transformation techniques to enhance agility, real-time visibility, and inter-agency coordination.

At the same time, the larger industrial environment is moving beyond Industry 4.0, focused on automation and cyber-physical systems and towards Industry 5.0. This novel paradigm replaces the human aspect of the loop with the focus on sustainability, resilience, and human-centeredness and technological efficiency (European Commission, 2021; Leng et al., 2022). Although the use of technologies like big data analytics and the Internet of Things (IoT) toward improving situational awareness in disaster response is becoming more popular (Dubey et al., 2020), the situation is not just a technological one. It entails a reconsideration of the way human operators engage with intelligent systems to guarantee the viability in case of disruption (Ivanov, 2023).

Humanitarian organizations do not have a roadmap towards digital transformation, although such technologies hold potential. Lack of skills, governance limitations, and the challenge of ensuring interoperability amidst fragmented aid networks are the common stalling factors of adoption. Researchers have found critical success factors (CSFs) in the commercial sector including leadership support, data governance to facilitate this transition. As an example, Sarkar et al. (2024) have recently applied a hybrid decision-making approach to simulate the CSFs to transform Industry 4.0 into Industry 5.0 in smart manufacturing.

Nevertheless, there is still a huge gap in the literature: no similar research has been done on humanitarian logistics. Although recent reviews found that there are obstacles to digital adoption in humanitarian supply chains (Birkel & Hartmann, 2020), the reason behind human-centric transition to Industry 5.0 is not specified. It is a significant shortcoming that should not be overlooked because the humanitarian sector is encountered with special ethical and operational restrictions in which commercial models cannot be directly used. To fill this gap, this paper determines and evaluates the key success factors that allow shifting to Industry 5.0 in humanitarian logistics.

2. Literature Review

2.1 Industry 5.0: The Human-Centric Shift

Industry 4.0 emphasized majorly on automation and cyber-physical productivity, however, Industry 5.0 has turned out to be an essential corrective action, where technology should not occupy the human needs, but act as an answer to them. According to the European Commission (2021), this change is not a technological breakthrough, but a value-driven process towards resilience, sustainability, and human-centricity. This transformation is crucial in the domain of logistics; it shifts the processes toward systems that can adjust to the disruption but maintain the importance of the well-being of workers (Leng et al., 2022). Ivanov (2023) also states that it is a crucial feature of supply chains under deep uncertainty, which is why it is very applicable to the context of humanitarian.

2.2 Digital Transformation in Humanitarian Supply Chains

Humanitarian logistics is a business that exists within conditions unfamiliar to the business industry: sharp fluctuations in demand, poor infrastructure, and the pressing need to save lives. Digital transformation in this case, therefore, is not so much about efficiency but about visibility and agility. According to the report State of Logistics and Supply Chain in the Humanitarian Context (2024), although the digitalization process is enhancing the sharing of information, the lack of collaboration is strong, and less than half of organizations are participating in shared planning. The sector faces challenges of systematic adoption in spite of the obvious advantages of technologies such as blockchain to enhance transparency and IoT to monitor in real-time. Kabra et al. (2023) found that, more frequently than the technical ones, strategic barriers are more detrimental to adoption, including the absence of top management support

and unclear vision. Equally, Birkel and Hartmann (2020) observed that the unrealized use cases tend to hinder the investment of IoT by humanitarian bodies.

2.3 Critical Success Factors (CSFs) for Transition

It is not a new area of research on commercial manufacturing to know what makes digital transformation successful. Sarkar et al. (2024) have shown that Industry 5.0 transition depends on the cause (such as leadership commitment and strategy) factors that create effects (such as technological adoption) factors. Modgil et al. (2022) also discovered that in unstable environments (such as the response to COVID-19), AI was not the main enabler of resilience, but the ability of the organization to utilize AI in decision-making.

The literature in the humanitarian situation, however, is disjointed. Although the studies have examined the obstacles to individual technologies, no framework has been developed, integrating the factors to facilitate a complete Industry 5.0 transition. The proposed study fills this gap by transforming the BWM-DEMATEL approach to the digital transformation of humanitarian assistance into a specific focus on the human-centric approach to digital transformation.

3. Methodology

To that end, this study adopts an MCDM approach to identify, prioritize and model out the interrelationships among these critical success factors in industries like humanitarian logistics which are driving the digital transformation. According to this article's methodology, data collection via expert judgment is similar to the method for Industry 5.0 BMS research in smart manufacturing (Sarkar et Al., 2024). Nonetheless, it has been smoothed for both humanitarian logistics with this model and also extended to incorporate diagramming of cause demands quality to be user-friendly; please review our most recent progress in this area.

3.1 Identification and Finalization of CSFs Using CSFT

Critical Success Factor Theory (CSFT) (Rockart, 1979) provides the conceptual foundation for deriving context-specific factors which are critical to the success of an organization. Following CSFT, the study began by conducting a structured literature review across humanitarian logistics, Industry 4.0/5.0 technologies, digital transformation, and ethical considerations for vulnerable populations.

The selection of the experts was done based on a purposive sampling strategy as it requires specialists domain knowledge). The inclusion criteria required experts to possess at least five years of professional experience in humanitarian logistics, disaster response coordination, humanitarian technology deployment, or policy-level decision-making related to emergency supply chains. The final panel comprised of 20 experts, including senior logistics coordinators of international NGOs, representatives of United Nations humanitarian clusters, representatives of governmental disaster management agencies and managers of humanitarian technology solution providers.

The selected sample size aligns with previous BWM- and DEMATEL-based studies, for which an expert panel generally consisted of 10 to 30 decision-makers (Rezaei, 2015; Tzeng et al., 2007; Sarkar et al., 2024) to provide a satisfactory balance between analytical robustness and practical feasibility. Also, the range of organizational backgrounds and geographical exposure of experts contributes to the potential transferability of results beyond a specific humanitarian context. Each expert was asked to:

- Validate etc. the CSFs in question and to suggest additions or modifications
- Assess the relevance of each CSF to Industry 5.0 transition
- Confirm the final list of 17 factors

Table 1. CSFs for Industry 5.0-Enabled Humanitarian Logistics

CSF No.	Critical Success Factor (CSF)	Sources
H-CSF1	Aligned humanitarian strategy for I5.0	Sphere Standards (2018); Altay & Green (2006)
H-CSF2	Top management and donor support for digital adoption	Van Wassenhove (2006); Jahre et al. (2020)
H-CSF3	Field staff acceptance and alignment for digital transformation	Dubey et al. (2018); Kembro & Selviaridis (2022)
H-CSF4	Security & privacy for vulnerable population data	Voigt & Von dem Bussche (2017); Altay et al. (2018)
H-CSF5	Scalable digital architecture across agencies and countries	UN OCHA (2019); Jensen & Hertz (2016)
H-CSF6	Legal, ethical and humanitarian compliance for I5.0	ICRC (2019); Cows & Floridi (2018)
H-CSF7	Upskilling, reskilling and talent retention	Oloruntoba & Gray (2006); Wuest et al. (2020)
H-CSF8	Cost, funding and donor flexibility for innovation	Tatham & Kovács (2010); Sandvik et al. (2017)
H-CSF9	Cultural collaboration & community engagement	Heaslip et al. (2018); Whittaker et al. (2015)
H-CSF10	High-powered analytical capability for real-time situational awareness	Dubey et al. (2018); Ben-Tal et al. (2011)
H-CSF11	Environmental & sustainability considerations	Van Wassenhove & Pedraza-Martinez (2012); Kovács & Spens (2011)
H-CSF12	Adoption of advanced technologies for humanitarian value	Jensen & Hertz (2016); Tatham et al. (2017)
H-CSF13	Process automation with human oversight	Altay et al. (2018); Sousa & Rocha (2019)
H-CSF14	Sensitization toward human-centric sustainability & inclusion	Floridi (2018); Adel (2022)
H-CSF15	Inter-agency data interoperability & standards	UN OCHA (2019); Palen et al. (2010)
H-CSF16	Community trust in technology-enabled relief operations	Sandvik et al. (2017); Whittaker et al. (2015)
H-CSF17	Infrastructure robustness in fragile & remote environments	Jahre et al. (2020); Holguín-Veras et al. (2012)

3.1.1. Scales Used During Expert Elicitation

To maintain methodological rigor and ensure consistency across expert judgments, standardized measurement scales were applied for both the prioritization (BWM) and causal relationship mapping (DEMATEL) stages—drawing on established scaling procedures from Rezaei (2015), Saaty (1980), and Gabus and Fontela (1972) for the BWM phase, and from Tzeng et al. (2007) for the DEMATEL phase.

Table 2. Comparison Scale for BWM

Value	Interpretation
1	Equal importance
2	Between equal and moderate importance
3	Moderate importance
4	Between moderate and strong importance
5	Strong importance
6	Between strong and very strong importance
7	Very strong importance
8	Between very strong and extreme importance
9	Extreme importance

Table 3. Influence Scale for DEMATEL

Value	Influence Level
0	No influence
1	Very low influence
2	Low influence
3	High influence
4	Very high influence

3.2 BWM for CSF Prioritization

The relative importance of the CSFs was determined by means of the BWM. It was performed in four structured steps. Initially, each expert selected the most and least critical (Best, Worst) CSCs for realization of Industry 5.0-oriented digital transformation in humanitarian logistics. Second, experts identified the Best CSF only as against all others in the 1–9 scale shown in Table 2, creating the vector for Best-to-Others comparisons. Finally, every CSF was contrasted with the Worst CSF using the same scale as Others-to-Worst comparison vector. Ultimately, all of these inputs were integrated with a constrained optimization model to obtain a consistent and normalized weight vector of each expert. The individual expert weights were then averaged to yield group-level CSF weights. Experts identify:

- Best (most important) criterion
- Worst (least important) criterion

and then provide two comparison vectors:

- Best-to-Others vector $A_B = (a_{B1}, a_{B2}, \dots, a_{Bn})$
- Others-to-Worst vector $A_W = (a_{1W}, a_{2W}, \dots, a_{nW})$

These inputs are used to solve a constrained optimization model to determine the optimal weights w_1, w_2, \dots, w_n .

Let:

- $C = \{C_1, C_2, \dots, C_n\}$ be the set of CSFs
- C_B be the Best criterion, with index B
- C_W be the Worst criterion, with index W

Experts provide:

$$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn}), a_{Bj} \in \{1, 2, \dots, 9\}$$

$$A_W = (a_{1W}, a_{2W}, \dots, a_{nW}), a_{jW} \in \{1, 2, \dots, 9\}$$

The deterministic BWM model minimizes the maximum absolute deviation ξ :

$$\min \xi$$

Subject to:

$$\left| \frac{w_B}{w_j} - a_{Bj} \right| \leq \xi, j = 1, \dots, n$$

$$\left| \frac{w_j}{w_w} - a_{jw} \right| \leq \xi, j = 1, \dots, n$$

$$w_j \geq 0, \sum_{j=1}^n w_j = 1$$

This yields an optimal weight vector:

$$w^* = (w_1^*, w_2^*, \dots, w_n^*)$$

For group decisions (20 experts), weights are aggregated using the arithmetic mean:

$$\bar{w}_j = \frac{1}{E} \sum_{e=1}^E w_j^{(e)}$$

3.3 DEMATEL for Modeling Causal Relationships

After CSFs were prioritized based on the BWM approach, the casual structure and each CSFs interdependencies on others, were investigated using the DEMATEL method. Using the 0–4 influence scale as summarized in Table 3, experts assessed the direct effect of one CSF on another. Direct influence matrices of all experts were calculated, they were added and normalized for the total relation matrix. Based on this matrix, two important indicators were computed, namely: prominence (D + R), which indicates the overall importance of each CSF in the system and relation (D – R) which indicate whether a CSF is mainly a cause (driver) or effect (outcome). This process allowed for a systematic classification of CSFs groups as a cause or effect and helped in creating causal relationship diagrams. Let:

- $X = [x_{ij}]_{n \times n}$ be the direct influence matrix, where:

$$x_{ij} \in \{0, 1, 2, 3, 4\}, x_{ii} = 0$$

- Normalize the matrix:

$$N = \frac{1}{\max_i \sum_j x_{ij}} X$$

- Total relation matrix:

$$T = N(I - N)^{-1}$$

Where:

- $D_i = \sum_j t_{ij}$ (row sum: influence given)
- $R_i = \sum_j t_{ji}$ (column sum: influence received)

Prominence:

$$P_i = D_i + R_i$$

Relation:

$$E_i = D_i - R_i$$

Interpretation:

- If $E_i > 0$: CSF is a Cause
- If $E_i < 0$: CSF is an Effect

4. Results

This study utilized the combined Best–Worst Method (BWM) and DEMATEL analysis to present the results of an evaluation of the critical success factors (CSFs) in terms of both relative importance and the presence of any causal relationships. We provide a foundational understanding of the priority factors, as well as the magnitude and nature of their direct influence and structural interactions that will drive Industry 5.0–aligned digital transformation in humanitarian logistics through the below figures.

Firstly, BWMs were derived to evaluate the importance ranking of each CSFs through responses from 20 experts (Fig 1). Higher weight is assigned to indicators related to leadership engagement, trust in the community, workforce readiness for policing, capacity for data-driven decision-making, and ability to collaborate effectively; these are thereby suggested to be the most recognized central indicators of success in digital transformation efforts. In contrast, enablers around procedural automation, long-term sustainability and cultural adaptation seem to rank lower, implying that these elements become relevant only later, when core foundational enablers have been laid out.

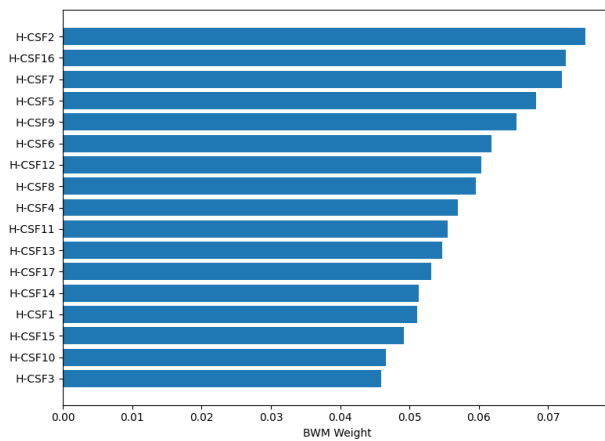


Figure 1. CSF importance ranking derived using

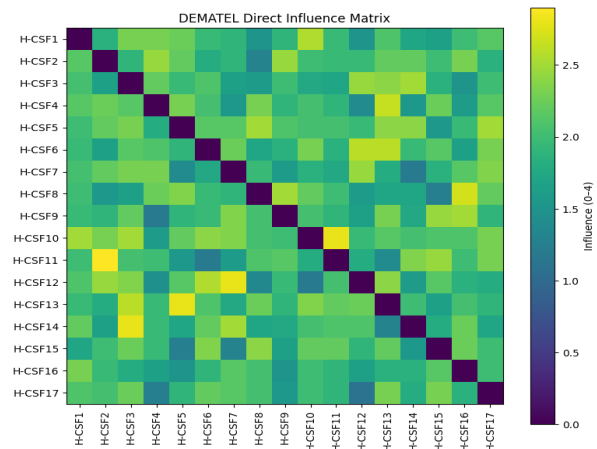


Figure 2. DEMATEL direct influence matrix of CSFs.

the Best–Worst Method (BWM).

In the DEMATEL direct influence matrix (Figure 2), based on 0–4 expert rating scale, we visualize how strongly each CSF influences others. The heatmap indicates a tightly coupled system where the technology- and governance-oriented elements, especially analytical capacity, cyber security, interoperability, and alignment driven by leadership-exhibit more intense and wider-spanning ecosystems of influence. This indicates that enhancements in these factors will likely propagate through the broader humanitarian logistics system, allowing for downstream improvements in resilience, efficiency and collaboration.

The DEMATEL impact-relation map in Figure 3 provides a simple classification of CSFs in Cause-and-Effect groups. An example of these drivers in the system includes analytical capability, leadership and donor support, privacy and security practices, and cross-agency collaboration mechanisms-all of which are in the upper half of the diagram (i.e., are associated with positive relation values). All these factors contributed positively to the wider system. On the other hand, items under the axis (with negative relation values) are regarded as realizations and encompass staff capacity, sustainability improvement and long-term resilience and community involvement. They are affected by driver factor trends and are likely to change over time, becoming more pronounced as digital transformation matures.

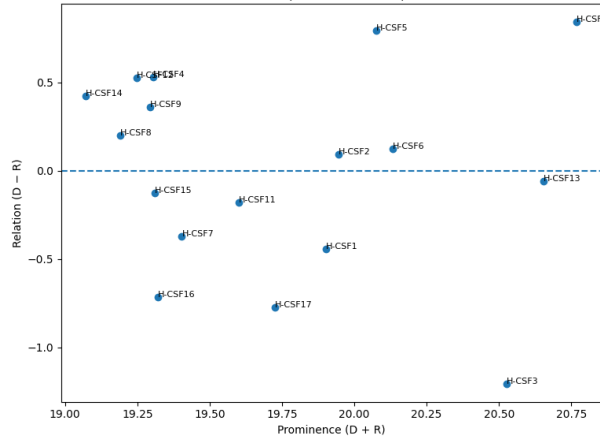


Figure 3. DEMATEL Impact-Relation Map (CSFs)

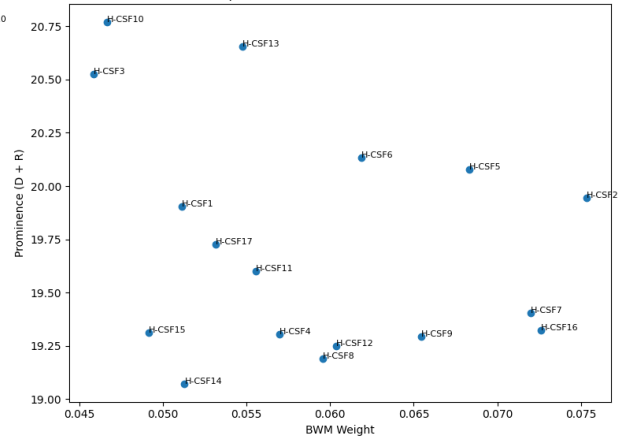


Figure 4. Relationship between CSF Importance (BWM) vs Prominence (DEMATEL)

Finally, combining plot of BWM vs. DEMATEL (i.e. Figure 4) overlap importance (BWM weights) to prominence (DEMATEL $D + R$) to common plot only for the factor that were identified as highly important and each of them were central in the whole system. Pointed out on the plot, it indicates that analytical capability, leadership commitment, workforce readiness and mechanisms that build trust exist in the upper part of both dimensions and are therefore key strategic building blocks. On the other hand, low importance and low prominence factors represent long-term capabilities that develop over time and are not immediate priorities.

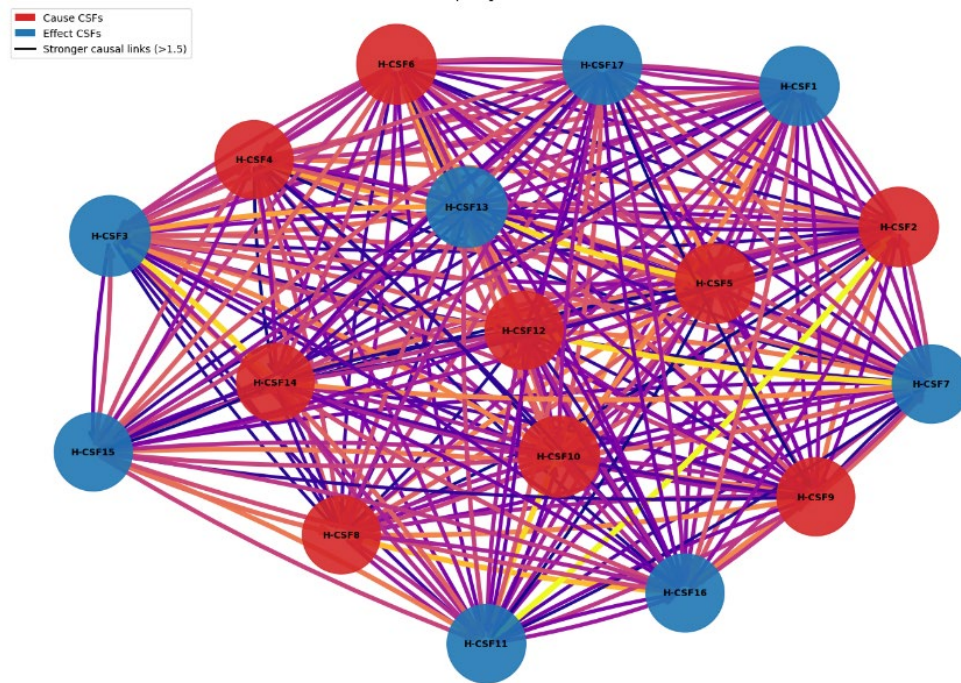


Figure 5. Causal Relationship Diagram of CSFs (DEMATEL-Based)

The network causal relationship map derived from DEMATEL analysis is shown in Figure 5. Figure 5: Causes CSFs are represented by red while Effects is shown in blue; node size reflects prominence and edge width distance to the direct cause (a function of the strength). The network diagram depicts a tightly integrated web of factors suggesting widespread interdependence of digital transformation for humanitarian logistics across organization, technology and human-oriented domains. The most influential upstream pathways (darker and thicker edges) mainly emanate from the driver factors, suggesting that improvements in leadership engagement, privacy and security practices, decision analytics of data use, and inter-organization sharing of broad sectors appear to be transmitted more throughout the

system. On the other hand, there are several incoming links to the effect factors showing a reliance on upstream drivers. The dense structure of the network highlights that successful Industry 5.0 transformation must be a coordinated activity, where interventions in high-impact driver areas simultaneously reinforce downstream aspects inclining towards sustainability, staff development, resilience and community trust. In summary, Figure 5 supports earlier results by illustrating the system-wide centrality gains delivered by the leading driver CSFs. The results of this study are in line with previous Industry 5.0 studies in manufacturing contexts and the identification of leadership commitment, analytical capability and data governance as key driver factors (Sarkar et al., 2024). However, the humanitarian logistics context raises more stringent requirements than commercial systems in terms of ethical considerations, data privacy for vulnerable populations, and fluency, and interoperability with the other in-the-field agencies. It also emphasizes the need to design Industry 5.0 frameworks to accommodate sector-specific operational and ethical parameters, rather than simply transferring models from profit-driven supply chains.

5. Conclusion

This study investigated the critical success factors (CSF) that enable Industry 5.0 in humanitarian logistics to undergo digital transformation. The research employed a mixture of twenty sectoral specialists' insights and the BWM and DEMATEL to establish both the relative worth and origin of factors shaping 5.0 readiness. The findings showed that factors particularly leadership and donor support among stakeholders, trust and dedication, data-supported analysis as well as the ability to make knowledgeable decisions based on that data, and the exchange of inter-agency information are currently seen as the most influential components for starting and maintaining transformation. The outcome of DEMATEL study further showed that these factors act as key intermediaries delivering strong causal thrust through the big picture, and so shaping downstream results such as environmental sustainability, innovation, adaptive capacity of providers and community trust. The causal network diagram showed the close integration of the humanitarian logistics environment with other environments, and confirmed that enhancing analytical capability, security and privacy protection mechanisms, and across organizations, sets off widespread positive chain-reinforcing effects. Overall, the results suggest that humanitarian organizations moving towards Industry 5.0 have to prioritize basic human-centered, analytical and managerial capabilities at their core to create secure, well-adapted digital ecosystems with an ethical backbone.

6. Future Work

Though this study offers a verified and structured framework for humanitarian logistics to enter Industry 5.0, research remains needed to find areas in the future. Manifold directions for future research exist. Extending the expert pool both geographically and institutionally is one of them. Such an approach not only would improve generalizability, it could also reflect humanitarian operations carried out in a variety of regions and across different organizational styles. A further methodological extension might be to incorporate fuzzy logic, probabilistic models or Bayesian approaches into the assessment. In particular, such adjustments are designed to reflect the realistic uncertainty, subjectivity, and inherent variability that emerges in expert assessments in complex humanitarian environments. One possible future branch of research is to carry out sector-specific studies on fields such as health logistics, food distribution or emergency telecommunications, revealing changing law grain systems for each part of the humanitarian sub-system. Furthermore, Connecting CSFs with performance metrics that are measurable such as distribution lead time, volume covered, resource efficiency and carbon emissions which would allow sharper eyed operational insights to be deduced from the concepts. Longitudinal studies, or implementation studies with real examples of success (and failure), might help us understand more deeply the transformation pathways, environmental barriers and collective learning of organizations. Lastly, in future research we may look more closely at such emerging Industry 5.0 technologies as explainable AI and cognitive robots what's happening with their introduction, ethical questions raised by them, value they give to humanitarian operations. If taken together, this series of research extensions would build a better evidence base, letting us construct digital transformation strategies for humanitarian logistics that are more firmly entrenched in evidence and more suitable across different environments than purely conceptual principles.

Acknowledgements

Authors would like to express gratitude to all the experts from international NGOs, UN logistics clusters, governmental disaster management agencies, and humanitarian technology providers whose insights and professional experience greatly enriched this research.

Funding Statement

This research did not receive any external financial support.

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