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An integrated framework for digitalization of humanitarian supply chains in post COVID-19 era

Anchal Patil [a], Vipulesh Shardeo [b], Ashish Dwivedi [c], Sanjoy Kumar Paul [d,*]

[a] Christ University, Bengaluru, India
[b] Lal Bahadur Shastri Institute of Management, New Delhi, India
[c] Jindal Global Business School, O.P. Jindal Global University, Sonipat, India
[d] UTS Business School, University of Technology Sydney, Sydney, Australia

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ABSTRACT

Digital Supply Chains (DSCs) are transforming industries across various domains. Digitalization can improve coordination, increase data collection and retention capacities, enhance funding mechanisms, and improve operational performance and resource utilization. However, DSC adoption is constrained by lack of funding, operational complexities, infrastructure issues, etc. Thus, the need emerges to explore the digitalization of the Humanitarian Supply Chain (HSC) and provide solutions that can ease the adoption of DSC. In this study, a framework is created to facilitate the digitalization process of HSC in post COVID-19 era. Nineteen related drivers are identified with the potential to digitalize the HSC. The drivers are identified from the previous literature and finalized with the assistance of HSC stakeholders. A Principal Component Analysis is carried out to discover the most pertinent drivers from the identified list of drivers. A Kappa analysis is adopted to perfect the priority map of the digitalization drivers. Further, the neutrosophic DEMATEL methodology is adopted to prioritize the potential drivers and find their dependency on each other. The results from the study indicate that the most influential drivers fall under the operational and technological categories. However, the social drivers have the potential to play a significant contribution in an effort to HSC digitalization. In addition, the study presents strategies for enhancing funds collection and data management using emerging technologies. These strategies can assist HSC decision-makers in formulating relevant policies and strategic interventions.

1. Introduction

Humanitarian Supply Chain (HSC) is a complex system comprising a variety of stakeholders interacting in imperative and uncertain circumstances [1,2]. The HSC network must ensure timely delivery of relief material to disaster victims. Considering the critical function of the HSC, stakeholders require a robust and resilient information management system for executing relief operations. Further, the demand for visibility and transparency has increased in recent years [3]. In this context [4], examined the role of digitalization and reported that information systems could reduce corruption and improve management. Information systems are essential in integrating various stakeholders and processes besides collecting, processing, and sharing information across the HSC [5]. In the past decade, numerous Information Technology (IT) advancements have occurred and transformed business processes [6]. For example

* Corresponding author.
E-mail addresses: patil.anchal@gmail.com (A. Patil), vipuleshshardeo@gmail.com (V. Shardeo), ashish0852@gmail.com (A. Dwivedi), sanjoy.paul@uts.edu.au (S.K. Paul).

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[7], studied the Internet of Things (IoT) with blockchain to manage asbestos waste treatment and expressed several benefits regarding data security, availability and regulations [8]. introduced the cloud supply chain and reported benefits, including resilience, visibility, and transparency. Similarly [9], presented the transformation in the manufacturing process including personalization with the adoption of artificial intelligence (AI).

The digitalization process can potentially enhance the supply chain's operational efficiency and bridge leakages across the value network [10]. Several benefits have been attributed to an efficient information system for the supply chain. For example, information sharing improves performance by minimizing the bullwhip effect [11]. The information system improves responsiveness and flexibility in the supply chains [12]. Derived visibility and coordination reduces the supply chain risk [13]. However, Digital Supply Chains (DSCs) are still in a nascent phase, and the benefits of digitalization remain underutilized [14]. In this context, the Humanitarian Digital Supply Chain (HDSC) is seen as an ecosystem of ubiquitous information technologies, working synergistically to support the implementation of relief operations.

There are few studies that explored the implementation of technologies, such as blockchain, big data, and social media, in HSC domain [15]. examined the application of blockchain as an enabler for swift-trust and resiliency in HSCs [16]. examined the importance of big data in improving HSC efficiency [17]. designed a hybrid system architecture for resource management in HSC using Radio Frequency Identification Devices (RFID) [18]. analyzed the resource requirement considering Internet of Things (IoT)-based rescue operations. A recent review by Ref. [19] highlighted the need to integrate DSC technologies and social media for efficient relief operations.

Evidently, the understanding of HSC digitalization and its effect on the HSC remains unplumbed [20]. Analyzing the HSC literature post-COVID-19 [21], investigated the contribution of digital advancement in enabling circularity, coordination, and managing disruptions. The requirements to adopt digital technology in HSCs have been highlighted by several researchers [20,22]. Highlighting inadequate coordination and information exchange during the COVID-19 pandemic [23], explored the applications of blockchain-enabled HDSC and suggestedstrategic approaches to digitalize the HSC. Considering the highlighted requirements, this study examines the potential drivers of DSC in the domain of HSC. The following research objectives (ROs) have been formulated:

RO1: To identify and model the drivers of HSC digitalization in the post COVID-19 era;

RO2: To create a framework to facilitate adoption of digital technologies in relief work; and.

RO3: To provide managerial implications and insights related to information systems for HSC stakeholders.

These ROs were addressed by adopting a systematic research methodology. Initially, a detailed exploration of different applications and pilots related to DSC was conducted. Then, the study identified different drivers for adopting and disseminating digital tools in the HSC. To that effect, this study developed a framework to prepare a prioritized list of drivers. This list of prioritized drivers aims to assist decision-makers in adopting DSC tools. In addition, the cause-effect interactions among the drivers was extracted to identify most suitable drivers of DSC.

The rest of the manuscript is distributed as follows. Section 2 explores the literature related to information systems and the HSC and identifies drivers and research gaps. Section 3 presents the research methodology. Section 4 presents the result analysis. Discussion and managerial implications are provided in Section 5. Finally, the conclusion and potential future research directions are presented in Section 6.

2. Literature review

In this study, the literature review comprises two stages. The first stage highlights the theoretical background associated with information systems and the HSC. The second stage presents previous studies related to DSC adoption in supply chains. Based on the literature survey, research gaps and contributions are presented.

2.1. Information systems in the HSC

This sub-section describes the applications of different advanced technologies for variety of HSC operations. AI and Big Data have been substantially explored in the previous literature [24]. examined the interactions between supply chain agility and collaboration in building AI-driven Big Data Analytics Capability [25]. recognized the barriers to big data in the context of sustainable HSCs and modeled the interactions among the fifteen identified barriers with fuzzy TISM methodology [26]. introduced a conceptual framework for an integrated HSC enterprise resource system and validated the framework for the Greek refugee crisis. They found that improving lean operations for HSCs and optimizing resource planning are crucial. Similarly, Sigala et al. (2020) explored the design principles required for Enterprise Resource Planning (ERP) for the purpose of digitizing the operations considering Humanitarian Organizations (HOs). The study considered a case study comprising a humanitarian medical relief organization.

Similarly [27], proposed a model to improve the information flow in HSC through AI, blockchain, and 3D printing technologies. Their analysis reflects the potential to condense congestion in the supply chain. Further [15], proposed a framework to comprehend how blockchain can affect swift trust and supply chain transparency among performers associated with disaster relief operations. Dubey et al. (2019) suggested a model to comprehend big data analytics capability under the scenario of disaster relief operations. The results construct an understanding of information processing competencies to shape trust and enhance collaborative performance. Similarly [28], conducted a systematic literature review of the HSC and the advancement of big data applications.

[29] presented a study to recognize the role of big data and predictive analytics in improving coordination in HSC. Further [30], empirically investigated technology implementation performance in HOs [31]. examined the interactions between flexibility, IT utilization, and performance in the context of HSC. The results suggest that the agility and flexibility of HOs are linked with IT employment [32]. analyzed the adoption of IT tools for enhancing supply distribution and data management in camp management. In this

study, a cooperative game theory model was implemented. Further [17], designed an architecture for resource information management systems in the context of humanitarian logistics centers. When designing the architecture, "passive RFID reader as a sensor" and "active tag as a sensor" were employed as the two new concepts.

2.2. Current state of DSC adoption in supply chains

In the present era, DSCs are one of the industry's swiftest developing and most disruptive developments [33]. DSCs adopt smart technology competencies to create supply chains that are collaborative and efficient. The employment of digital technologies is important to support operational events during unfavorable situations (Dubey et al., 2019). This section highlights potential studies related to digital technology implementation in supply chains.

[34] studied the impact of digital technologies implementation in manufacturing organizations and found that technological intelligence and supply chain cooperation as two essential variables for implementing digital technologies in supply chains. The impact of digital technology implementation on improving disruption events and sustainability characteristics was studied [35]. [36] highlighted the advantages of digitalization in improving healthcare delivery, including both the internal and external digitalization paths. The predictors of electronic trading considering agricultural marketing were identified and a case study of an electronic national agriculture market was presented [37]. A study to review the potential contribution of digital technologies in the context of the agri-food sectors was performed and suggested that economic sustainability emerges as the strongest force, with less emphasis on social or environmental sustainability for technology adoption in agri-food sectors [38]. Also, Hopkins (2021) performed a study to understand the measures taken by an organization to confirm its employment of digital technologies and identified that organizational size is a factor in technology implementation. A study examined the role of digital technologies in reverse factoring implementation and found that the reverse factoring attributes in investigating the suppliers' trade-off behavior [39]. Similarly [40], performed a literature survey to analyze the factors that hindered the implementation of digital technologies in food waste management and demonstrated that environmental and technological factors are the most important.

[41] presented a study to track digitalization's progress in logistics and supply chains and described how digitalization had been implemented in the logistics and supply chain industry. A study inspected the effectiveness of sales force automation in a supply chain from a customer perspective using the Structure Equation Modelling (SEM) approach [42]. [43] presented a study to analyze the focus of organizations implementing Industry 4.0 practices and found that forced pressure diminishes the interaction of exploration to implement Industry 4.0 and DSCs. The impact of digitalizing supply chains on selected lean operations practices was studied and reflected that e-business technologies positively influence internationalization when investments are made in digital services [44]. [45] explored a case study to illustrate the managerial perspective for Industry 4.0 adoption in manufacturing value chains and to resolve potential issues towards adopting digital technologies. The potential challenges in digital technology adoption were investigated considering the case of developing countries using a system dynamics approach to identify domains that support agri-food sustainability [46]. Also [47], explored the impact of big data analytics and identified forty-three challenges associated with developing Big Data Analytics in supply chains.

2.3. Review of drivers toward digitalization in HSCs

A reformation towards digitalization requires intense modification in the entire organization. The different operations and processes in organizations were transformed with the implementation of digital technologies. There are various drivers that can influence the shift towards digitalization in HSCs. Consequently, it is essential to investigate the potential drivers of digitalization. With this objective in mind, a literature review focusing on digitalization in the HSC domain has been conducted, and a few of these are highlighted in the preceding sections. Based on the detailed literature analysis, it can be summarized that numerous researchers have highlighted the adoption of digital technologies in supply chains [34,48]. Several studies identified the challenges and issues that hinder the implementation of digital technologies [49,50]. Some studies implemented the Multi-Criteria Decision Making (MCDM) approaches to assess challenges [51,52]. While various studies were relevant to digital technologies and supply chains, very few addressed their links with the HSC. Moreover, exploring drivers for implementing digitalization in HSCs is a significant and practical research problem.

The literature-extracted drivers were either proposed by the literature or discussed from the authors' perspective. Based on that, a preliminary list of drivers has been extracted and discussed with the experts selected for this study. A number of drivers were eliminated based on the recommendations of experts, and the finalized drivers are listed in Table 1.

3. Research methodology

The prime objective of this study is to identify the influential weights of digitalization drivers in the context of HSCs. Initially, 19 drivers were identified from a literature survey and finalized after consultation with experts. Next, Principal Component Analysis (PCA) was adopted to identify the potential drivers. Further, Kappa statistics, a consensus-building tool, was adopted to categorize the identified drivers. The analysis categorized drivers towards digitalization of HSCs under four categories (Technological, Organizational, Operational, and Social). Afterward, an integrated neutrosophic DEMATEL was employed to construct a cause-and-effect diagram among the drivers. The following sub-sections describe the data collection process and different methodologies adopted to model these drivers. The methodological flowchart is presented in Fig. 1.

Table 1
Drivers toward digitalization in the context of HSC.

Code	Drivers	Definition of the driver	References
D1	Ease of documentation	DSCs enhance the widespread availability of information across the network, thus reducing the requirement for paperwork and making the process efficient.	[14]; Deepu & Ravi (2021) [53];
D2	Agile value chain	Timely availability of appropriate information increases HSC capability to suitably cater to uncertain and chaotic circumstances. This benefit qualifies the agile value chain as a potential driver of digitalization.	[27,54]
D3	Appropriate resource management	The convergence of multiple actors in the aftermath of disasters results in the repetition of activities. A coordinated action plan reduces the risk of repetition. Further, optimization models supported by DSC can improve resource allocation.	[55,56]
D4	System responsiveness	Donors are the secondary consumer of HSC and victims are the primary consumer. Maintaining responsiveness to multiple disconnected stakeholders requires integration. The DSC facilitates the efficient execution of activities in an integrated environment, leading to improved system responsiveness.	[57,58]
D5	Ease of performance monitoring	Data retention and lack of IT systems emerged as one of the most significant barriers to performance monitoring. Digitalization can enhance the efficacy of performance measurement systems by improving the fluidity of data.	[59,60]; Moktadir et al. (2022)
D6	Automated business process	Automated decision-support systems facilitated by DSC can efficiently execute processes and activities, thus reducing the risks and delays associated with human qualitative judgment.	[61,62]s
D7	Inventory control and planning	Inventory control and planning in HSCs counters several uncertain circumstances due to short lead time, unknown demand, and scarce resources. These situations require efficient information systems to suitably execute resource management activities.	[63,64]
D8	Tracking and traceability	DSC facilitates real-time monitoring of products, improving resource utilization and timely delivery in the HSC.	[27,65–67]
D9	Data transparency and security	Several instances of misuse of victims' data are evident in the literature. Further, instances of corruption hamper humanitarian work. Thus, humanitarian data needs a transparent and secure environment. This can be supported by technologies such as blockchain.	[15,68–70]
D10	Building trust and synergy among stakeholders	Trust is sought as a prerequisite for supporting long-term collaboration. Further, the mismatch of size and goals for varying HOs hampers the coordination process. DSC-supported coordination improves trust and helps in aligning the goals.	[71–73]
D11	System flexibility	A self-adapting system improves the ability to better implement the ever-changing relief operations dynamics.	[24,74,75]
D12	Enhanced visibility	HOs struggle with scarce resources while allocating funds for administration and secondary activities such as performance monitoring, reporting, and appeal processes. Many practitioners believe that serving disaster victims is the primary task and other activities can be delayed. However, this hampers the visibility and resultant earning of HOs. DSC tools can increase information availability, while better resource allocation and appropriate planning can assist in maintaining better visibility.	[13,25,29,60, 76,77]
D13	Prudent analytical capabilities	Forecasting demand for disaster victims and resource planning is a challenging task. DSCs hold the potential to better utilize the available data. Further, a knowledge-based system supported by DSC can improve analytical capabilities.	[29,78–81]
D14	Efficient risk management	HSCs operate in a chaotic and ever-changing environment. Therefore, it becomes essential to incorporate risk prediction, avoidance, and minimization policies, which require robust information systems for planning and execution.	[82–84]
D15	Efficient aid management	HOs are under pressure to provide accountability in a competitive humanitarian sector. Further, the customs, international transactions, and regulatory and bureaucratic hurdles create complexities for the aid flow. DSC is sought as an improvement for better aid allocation, monitoring, and reducing intermediaries.	[85–87]
D16	Resilient information flow	IT systems in a post-disaster operative environment often have limited functionality. Thus, HSCs require innovative IT solutions for maintaining the information flow.	[88,89]
D17	Effective warning and evacuation system	Efficiency of evacuation activities depends upon the timely disbursal of information. Thus, data collection, processing, and disbursal must be effective to reduce the disaster hazard.	[90–92]
D18	Sustainability-focused practices	Sustainability-specific practices are often ignored or receive limited attention in HSCs. The stakeholders can improve the monitoring activities with the help of DSCs to extend sustainability practices. Further, DSCs can help analyze practices hampering the environment and develop workarounds.	[2,93,94]
D19	Favorable strategies to link digitalization	Digitalization assists in improving the effectiveness and competitiveness of supply chains. There is a requirement to frame strategies for digitalization in HSCs.	[95,96]

3.1. Data collection and selection of experts

The data collection process took place in several rounds. The primary data source was published articles, HOs reports, blueprints, white papers and humanitarian experts' opinions. First, a 15-member committee comprised of experts committed to humanitarian work and application development. The interviewees were pre-briefed regarding the purpose and scope of the study. The experts provide various insights regarding the drivers' influence, inter-relationship, and interaction with other essential HSC functions. This effort aimed to extract a holistic overview of DSC adoption in HSC and develop recommendations.

Humanitarian operations have seen rapid growth due to increased disasters and conflicts worldwide. HSCs are expected to become more structured, efficient and resilient. The digitalization of HSC is inevitable and reported to bring sustainable performance improvement. Thus, this study considered professionals with hands-on knowledge in HSC. Experts' experience and their positions were considered throughout the panel selection process. The HOs involved a wide spectrum of experts, from field workers to high management. This wide range of job titles allowed greater insights into the digitalization process of HSC.

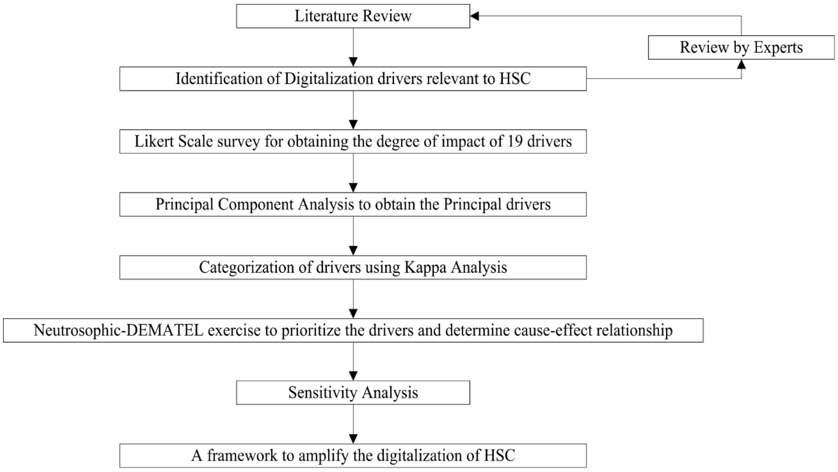

Fig. 1. Research methodology.

Initially, the authors identified several potential drivers from the previous articles and compiled a list of 19 drivers. The experts were consulted for the validation of drivers. The experts were also asked to offer any additional aspects of drivers. Each expert thoroughly evaluated the extracted drivers and their various dimensions. This process helps in defining and finalizing drivers for further analysis. After finalizing the drivers, the authors conducted a Likert scale survey to identify the principal drivers. The respondents were asked to rate drivers' degree of influence on a scale of 1–5. A total of 320 respondents participated in the survey. The brief information of those 320 respondents is presented in Table 2. This process resulted in the extraction of 14 drivers based on the variance explained by them. A detailed explanation of the finalization of drivers is presented in sub-section 4.1. Further, these fourteen drivers were categorized into four segments considering their nature and scope. Kappa analysis was performed to validate the obtained categories. The data for the kappa analysis was collected from the experts, as shown in Table 3, using another Likert scale survey. Finally, a semi-structured close-ended questionnaire was used to gather data for the neutrosophic DEMATEL. The neutrosophic DEMATEL framework was used to create the second-round questionnaire.

3.2. Principal component analysis (PCA)

The plurality of drivers limits the scope of adoption. Thus, PCA was adopted in this study to reduce the drivers with similar scope or aspects. PCA is a multivariate data analysis method that is used for dimensionality reduction. The original variables were translated into a set of linear combinations and resulted in a new set of variables known as principal components [97]. In this study, PCA is used to select the highly correlated drivers. For a detailed description of PCA, readers are advised to refer to Refs. [98,99].

Table 2
Key information of the respondents for PCA analysis.

Work Experience (number of years)			
0–2	2–5	5–10	10 +
29.7%	32.6%	18.4%	19.3%
Domain			
NGOs	Aid organizations	IT industry	Researchers
60.8%	4%	23.9%	11.3%

Table 3
Details of the selected experts for DEMATEL and Kappa exercise.

No.	Sector	Position	Number of experts	Experience
1	Humanitarian Organization	Manager	1	8 Years
2	Humanitarian Organization	Founder	1	21 Years
3	Humanitarian Organization	Field Officer	4	4–13 Years
4	IT Industry	Developer	4	3–10 Years
5	IT Industry	Senior Manager	1	12 Years
6	Academic	Professor	1	10 Years
7	Academic	Research Fellow	2	4–6 Years
8	Donor	Manager	1	18 years

3.3. Kappa statistics

Kappa statistics is employed to ensure consensus among the decision-makers [100]. Initially, kappa statistics was used to check inner consistency, and since then, it has been largely practiced in management research [101–103]. This study uses kappa statistics to check the consensus on the categorical distribution of identified drivers. For a detailed description of kappa statistics, readers are advised to refer [60,103].

3.4. Neutrosophic DEMATEL

This study employs neutrosophic DEMATEL to compute the weights and develop a cause-and-effect diagram of drivers influencing digitalization in HSCs. Integrating neutrosophic numbers with DEMATEL enables to cater ambiguities caused due to human decisions. However, fuzzy logic and grey theory are largely practiced to address such concerns. Fuzzy logic is outlined as it cannot handle with non-membership and indeterminacy [104,105][106]. Neutrosophic sets represent real-world cases by compiling decision-making dimensions, which include truth, indeterminacy, and falsity [107]. introduced the neutrosophic approach, and has been largely used in MCDM problems. Further [108], introduced and applied the neutrosophic DEMATEL method for supplier selection. This study contributes to the literature by applying neutrosophic DEMATEL methodology toward digitalization in HSCs. Before applying the methodology, some preliminaries are presented in Appendix A. The steps of the adopted methodology are presented as.

Step 1. Develop a list*of decision criteria:* Identify the set of decision criteria, denoted by $C = \{C_1, C_2, \ldots, C_n\}$ where $n \geq 2$.

Step 2. *Construct pairwise comparison matrix:* The pairwise comparison matrix is formed by comparing one criterion with others adopting the linguistic scale shown in Table 4. The experts will provide the element X_{ij} to measure the influence of criteria C_i on criteria C_j. The value of X_{ij} will be $\tilde{0}$, if $i = j$. The comparison matrix can be expressed as:

$$A = \begin{pmatrix} X_{11} & \cdots & X_{1j} \\ \vdots & \ddots & \vdots \\ X_{i1} & \cdots & X_{ij} \end{pmatrix} \tag{1}$$

Step 3. *Transform into real numbers:* The values of the pairwise comparison matrix are to be transformed into real numbers using equation (2). The matrix can be denoted as:

$$B = \begin{pmatrix} Y_{11} & \cdots & Y_{1j} \\ \vdots & \ddots & \vdots \\ Y_{i1} & \cdots & Y_{ij} \end{pmatrix} \tag{2}$$

Step 4. *Obtain the aggregated matrix:* The real values of experts transformed in the previous step can be aggregated by taking the arithmetic mean.

$$\bar{B} = \begin{pmatrix} \bar{Y}_{11} & \cdots & \bar{Y}_{1j} \\ \vdots & \ddots & \vdots \\ \bar{Y}_{i1} & \cdots & \bar{Y}_{ij} \end{pmatrix} \tag{3}$$

Step 5. *Obtain Normalized Direct-Relation matrix:* The Normalized Direct-Relation matrix can be obtained employing equations (4) and (5).

$$M = \frac{1}{\max \sum_{j}^{m} \bar{Y}_{ij}} \quad where, 1 \leq i \leq m \tag{4}$$

$$N = M * \bar{B} \tag{5}$$

Step 6. Determine the*total relation matrix:* The total relation matrix, T, can be attained adopting equation (6).

Table 4
Linguistic scale and their corresponding neutrosophic number.

Linguistic Term	Single Valued Triangular Neutrosophic Number
No Influence	$\tilde{0} = \{(0,0,0); 0.50, 0.50, 0.50\}$
Low Influence	$\tilde{1} = \{(0,1,2); 0.30, 0.75, 0.70\}$
Medium Influence	$\tilde{2} = \{(1,2,3); 0.80, 0.15, 0.20\}$
High Influence	$\tilde{3} = \{(2,3,4); 0.90, 0.10, 0.10\}$
Very High Influence	$\tilde{4} = \{(4,4,4); 1.00, 0.00, 0.00\}$

$$T = N(I - N)^{-1} \tag{6}$$

where I is the unit matrix.

Step 7. *Determine the causal and effect drivers:* The causal and effect drivers can be figured by adding up rows (R) and columns (D) and can be shown in equations (7) and (8).

$$R = \left[\sum_{j=1}^{f} t_{ij}\right]_{f\times 1} \tag{7}$$

$$D = \left[\sum_{j=1}^{f} t_{ij}\right]_{1\times f} \tag{8}$$

Step 8. *Draw the cause-effect diagram:* The values of $R + D$ and R-D reflect the cause-effect interactions among the drivers, positive values of R-D present the causal drivers and negative values highlight the effect drivers.

Step 9. Obtain*the influential weights:* The influential weights of drivers can be determined adopting equations (9) and (10).

$$w_j = \sqrt{(R+D)^2 + (R-D)^2} \tag{9}$$

$$\widetilde{w}_j = \frac{w_j}{\sum_{j=1}^{f} w_j} \tag{10}$$

4. Result analysis

This section presents the results of the PCA, Kappa, and neutrosophic DEMATEL exercises. The results are synthesized in the form of a cause-effect diagraph and a priority list of drivers for digitalization in HSCs. Further, sensitivity analysis was conducted to verify the robustness of the model.

4.1. PCA

The PCA used a Likert scale to obtain the HSC experts' opinions on the driver's influences. The distribution of work experience for the respondents is highlighted in Table 2. A Kaiser-Meyer-Olkin (KMO) test was performed to check the sample's adequacy. The test put on the adequacy of 0.731, which is reported to be adequate for exercising a factor analysis [109]. The descriptive statistics of the samples utilized are presented in Appendix B.

The survey data were analyzed using the R software package. PCA adoption aims to extract the drivers that represent the most variation. Three tests can be executed to extract the principal components: the eigenvalue test, scree plot test, and the proportion of the variances illustrated by the components test [110]. The outputs of different tests are provided in Appendix B. The rotated component matrix shown in Table 5 highlights the Pearson correlation of variables with the components. Table 5,reflects that drivers 3, 6, 9, and 15 have a strong correlation with component 1. In the same order, the rest of the components can be correlated with the drivers. This step helps to exclude the least significant drivers. The drivers having correlation value ranges between +0.5 and −0.5 have been

Table 5
Rotated component matrix.

Drivers code	Component						
	1	2	3	4	5	6	7
D3	0.728						
D6	0.792						
D9	0.501						
D15	0.615						
D13		0.537					
D18			−0.669				
D19			−0.618				
D11				0.807			
D17				0.648			
D2					0.583		
D16					0.671		
D8						0.821	
D5							0.713
D10							0.538

removed due to a relatively weaker correlation. As a result, drivers D1, D4, D7, D12, and D14 were removed from the list of identified drivers.

4.2. Kappa analysis

In the second phase, the study categorized potential drivers into different groups. Four categories (Operational, Organizational, Technological, and Social) were identified for grouping selected drivers [111–113]. As mentioned in the research methodology, Kappa analysis was performed using feedback from the fifteen experts whose details are shown in Table 3. This set of respondents have been selected based on their expertise out of the 320 respondents consulted for PCA analysis. The kappa value calculated is 0.647, reflecting a considerable consensus among the experts. The input and calculation of the kappa statistics is shown in Appendix C. Based on the experts' feedback, PCA, and validation from kappa statistics, the final list of drivers of digitalization in HSCs with their categories is shown in Table 6.

4.3. Neutrosophic DEMATEL analysis

Neutrosophic DEMATEL analysis utilizes the responses from experts in the form of pairwise comparison. For this exercise, five experts (Experts 1, 2, 5, 6, and 8, as shown in Table 3) out of the 15 experts consulted for Kappa analysis are selected due to their specific expertise in the problem context. Following the methodology provided in Section 3.3, a cause-and-effect diagram was obtained for the drivers. The detailed stepwise calculation for Expert 1 is shown in Appendix D for reference. As shown in Fig. 2, the Y-axis shows the total effects of category *i*, given and received (R + D). The X-axis shows the aggregate contribution by category I on digitalization (R-D). Arrows represent the cause-and-effect relationships between different categories. The diagram reflects which technological category is the strongest driving element, whereas the operational category drives the social and organizational categories. It is apparent that the technological aspect of digitalization is the most influential driving element in HSCs. It is evident that the organizational drivers are most influenced by the other three categories. From the results, it can be inferred that HSCs must focus on developing field-ready technological solutions to benefit from the digitalization process. From different perspectives, it can be stated that the potential of digital technology can be harnessed only after successful application development, pilots, and testing, which will

Table 6
Final drivers of digitalization in HSCs with their categories.

Categories	Name of the drivers	Code
Operational drivers	System flexibility	D11
	Agile value chain	D2
	Appropriate resource management	D3
Organizational drivers	Building trust and synergy among stakeholders	D10
	Efficient aid management	D15
	Resilient information flow	D16
	Effective warning and evacuation system	D17
Technological drivers	Automated business process	D6
	Data transparency and security	D9
	Tracking and traceability	D8
	Prudent analytical capabilities	D13
Social drivers	Ease of performance monitoring	D5
	Sustainability-focused practices	D18
	Favorable strategies to link digitalization	D19

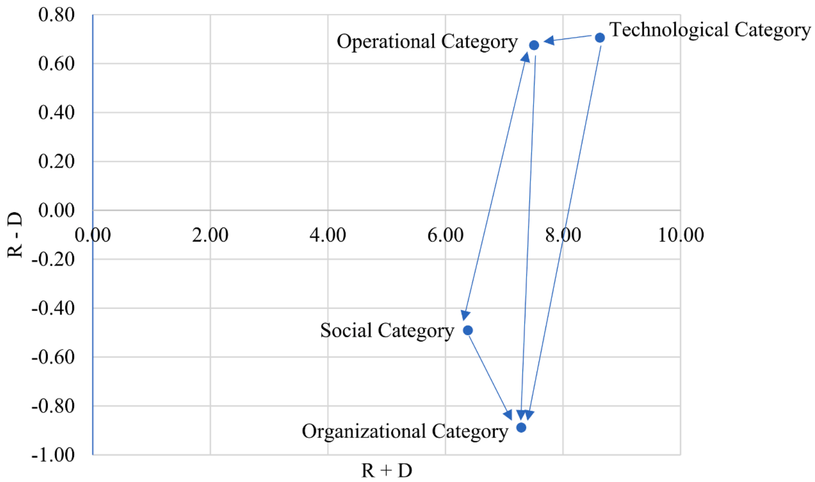

Fig. 2. Cause-and-effect diagram.

propagate the remaining identified drivers. Further, the results indicate that drivers under social and organizational categories are based on how other drivers influence the adoption process. Accordingly, it can be concluded that focusing on technological aspects will provide more benefits, while organizational complexities also need consideration in the adoption process.

Table 7 highlights the priority list of drivers according to their degree of influence on digitalization in HSCs. The local weights of categories reflect that the technological category ranked first, followed by operational, organizational, and social categories. However, drivers under operational categories placed 1st, 2nd, and 4th, making this category most influential. Even though the social category received the lowest rank, its drivers placed 6th, 7th, and 10th positions. This indicates that drivers under the social category hold the potential to play a crucial role in HSC digitalization.

4.4. Sensitivity analysis

The sensitivity analysis reflects the sensitivity of one driver over the other. The less sensitive driver contributes to the robustness of model. This study uses sensitivity analysis to check the robustness and biasness of the proposed neutrosophic DEMATEL model. The weights of the drivers/categories were varied to confront the impact on other drivers/categories [114].

A number of six scenarios were created by varying the weights of two drivers while the weights of other drivers were put to constant. In Scenario 1, the weights of operational and organizational drivers were alternated. Similarly, the weights of driver were substituted for all five scenarios. The variation in weights and ranking of the drivers in each scenario are reflected in Tables 8 and 9, respectively. Fig. 3 depicts the variation in influential weights of drivers where the influential weights of all other drivers modify in a similar manner. The ranking of other drivers slightly varied and rarely jumped one to two positions. The results from the sensitivity analysis confines that the drivers are less sensitive to the influential weights, which ensures that the suggested model is robust.

5. Discussion and managerial implications

COVID-19 magnified challenges in the already struggling humanitarian domain. Several humanitarian operations have been underfunded or ignored [115]. The shortfall of funding and challenges of the humanitarian response system highlights the need to restructure the existing HSC. Post-COVID-19, HSC reforms must include built-in resiliency and flexibility to handle large-scale system

Table 7
Priority list of drivers.

Category	Sub-factors	Local Weights	Global Weights	Rank
Operational (0.252)	System flexibility (D11)	0.337	0.085	2
	Agile value chain (D2)	0.295	0.074	4
	Appropriate resource management (D3)	0.368	0.093	1
Organizational (0.245)	Building trust and synergy among stakeholders (D10)	0.231	0.057	14
	Efficient aid management (D15)	0.269	0.066	11
	Resilient information flow (D16)	0.253	0.062	12
	Effective warning and evacuation system (D17)	0.247	0.060	13
Technological (0.289)	Automated business process (D6)	0.251	0.073	8
	Data transparency and security (D9)	0.230	0.067	9
	Tracking and traceability (D8)	0.256	0.074	5
	Prudent analytical capabilities (D13)	0.263	0.076	3
Social (0.214)	Ease of performance monitoring (D5)	0.311	0.066	10
	Sustainability-focused practices (D18)	0.344	0.074	7
	Favorable strategies to link digitalization (D19)	0.345	0.074	6

Table 8
Resultant change in influential weights of drivers in different scenarios.

	Normal	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
		F1–F2	**F1–F3**	**F1–F4**	**F2–F3**	**F2–F4**	**F3–F4**
D11	0.085	0.083	0.097	0.072	0.085	0.085	0.085
D2	0.074	0.072	0.085	0.063	0.074	0.074	0.074
D3	0.093	0.090	0.106	0.079	0.093	0.093	0.093
D10	0.057	0.058	0.057	0.057	0.067	0.049	0.057
D15	0.066	0.068	0.066	0.066	0.078	0.058	0.066
D16	0.062	0.064	0.062	0.062	0.073	0.054	0.062
D17	0.060	0.062	0.060	0.060	0.071	0.053	0.060
D6	0.073	0.073	0.063	0.073	0.062	0.073	0.054
D9	0.067	0.067	0.058	0.067	0.057	0.067	0.049
D8	0.074	0.074	0.064	0.074	0.063	0.074	0.055
D13	0.076	0.076	0.066	0.076	0.064	0.076	0.056
D5	0.066	0.066	0.066	0.078	0.066	0.076	0.090
D18	0.074	0.074	0.074	0.087	0.074	0.084	0.100
D19	0.074	0.074	0.074	0.087	0.074	0.085	0.100

Table 9
Resultant change in rankings of factors in different scenarios.

	Normal	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
		F1–F2	**F1–F3**	**F1–F4**	**F2–F3**	**F2–F4**	**F3–F4**
D11	2	2	2	8	2	2	5
D2	4	8	3	11	4	7	6
D3	1	1	1	3	1	1	3
D10	14	14	14	14	9	14	10
D15	11	9	8	10	3	11	7
D16	12	12	11	12	7	12	8
D17	13	13	12	13	8	13	9
D6	8	7	10	7	13	9	13
D9	9	10	13	9	14	10	14
D8	5	4	9	6	12	8	12
D13	3	3	7	5	11	6	11
D5	10	11	6	4	10	5	4
D18	7	6	5	2	6	4	2
D19	6	5	4	1	5	3	1

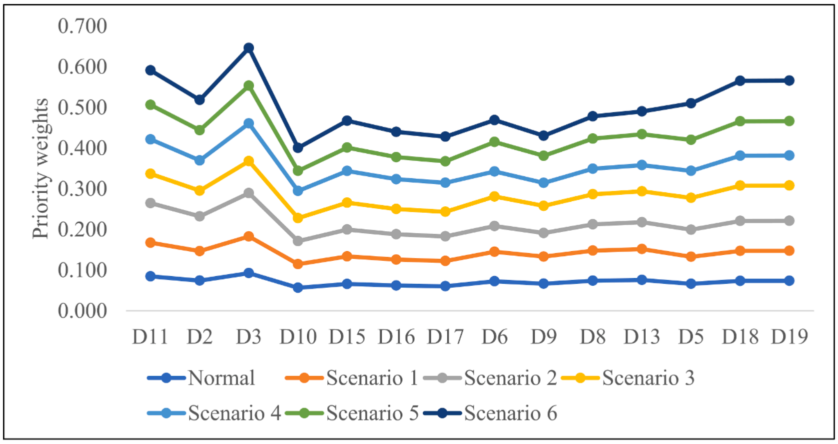

Fig. 3. Sensitivity analysis.

disruptions. The adoption of disruptive technologies can support transition to these reforms. Therefore, the present study explored the dynamics of digital technology adoption to assist humanitarian practitioners in transitioning toward the HDSC. The proposed framework provides new constructs regarding the most suitable adoption strategies and their implications for the sustainable performance of HSC.

Table 7 indicates that 'appropriate resource management (D3)' is the most influential driver, which falls under the operational category. Thus, this driver acts as the driving power of other drivers under the social and organizational categories. This finding relates to resource-constrained humanitarian operations. Several studies have highlighted resource convergence issues and termed it a secondary disaster [116,117]. The inappropriate convergence of relief material and volunteers creates operational complexities and wastes managerial efforts. This waste is attributed to limited coordination and lack of information [118,119]. These circumstances make digitalization critical for improvement in the HSC [21]. discussed secure transportation of medical supplies and food assistance to the disaster site. They seek an increased role of the neighboring countries as a hub for transporting the supplies. In this context, digitalization is essential for managing supply chain disruptions. Similarly [120], discussed the implementation of ERP in humanitarian operations and reported several design challenges related to resource management. They suggest developing an offline ERP system with a decentralized architecture. Along a similar line, one of the experts highlighted the requirement to integrate small stakeholders such as volunteers and local manufacturers in the HSC using DSC applications.

'System flexibility (D11)' placed second in the exercise. The incorporation of flexibility-focused policies extends the potential to respond to unforeseen circumstances. Thus, stakeholders are suggested to focus on developing digitally supported applications to incorporate flexibility in the HSC. A similar approach was suggested by Ref. [74] considering the case of a sustainable supply chain. Also [3], highlighted the role of flexibility in enabling technology-mediated integration. Both flexibility and digitalization have a complementary relationship and can substantially improve HSC performance. Thus, experts recommend enabling flexibility in HSC using digital tools.

Another driver under the operational category is the 'agile value chain (D2)', which received the fourth rank. This finding is similar to Ref. [15]; who reported the need for agility in HSC. Agile enables HOs to respond rapidly to demand fluctuations, supply disruptions, and suppliers' failures during relief response. Thus, HOs must incorporate agility practices to stay relevant and efficient in the competitive humanitarian domain [121]. One of the experts highlighted that adopting digital technology is essential to practice agility [122]. also presented similar findings that reflect how material and information flow can be improved with digitalization, making HSCs lean and agile. However, a rational approach is required before putting substantial investments in HSC digitalization from the perspective of agility. Experts suggest evaluating the investments and resultant improvement in the responsiveness of the HSC.

Considering the local weights of categories, technological category drivers emerged as the most influential. Under this category, 'Prudent analytical capabilities (D13)' received the third rank. In a stressful environment, volunteer bias and fatigue hinder decision-making process and negatively effect the operational effectiveness [123]. Further, the uncertainty of funds, resource availability, and convergence of inappropriate materials and transport network collapse create additional challenges for pre-planned operations [124–126]. Therefore, HSCs require a robust and adaptive information system that can foresee uncertain circumstances and efficiently propose appropriate action plans. The experts recommended that analytics capabilities must be strengthened by adopting an integrated big data AI system. In this context, HSC can benefit from the advances in deep learning and cloud computing.

The 'Tracking and traceability (D8)' feature of digital technologies ranked fifth in the list of drivers towards digitalization in the HSC. HSC operations involve the movement of medical and pharmaceutical products, requiring unique storage and monitoring facilities [127]. Various operational and sustainability issues have been reported relating to resource movement in HSC. Real-time monitoring of relief material movement is necessary to reduce the operational complexities and construct sustainable HSCs. Thus, HOs are advised to adopt the IoT, RFID sensors, and other digital tools in their logistics network. Further, stakeholders such as donors and governments should provide policy and monetary support to facilitate the digitalization practices. The researchers must construct innovative technological applications that can be deployed in crisis environments and accommodate to changes. Overall, these technologies, supported by appropriate resource management, leads to the digitalization of HSC and result in effective humanitarian operations. The proposed framework, as presented in Fig. 4, defines the linkages among the drivers.

During the interview process, various managerial implications were extracted, presenting insights on the adoption of DSCs. It is apparent that DSC adoption is inevitable. However, a cautious approach is required for DSC adoption. Decision-makers are required to clearly define the objectives before beginning the adoption process. Further, the alignment between different organizational goals and the interoperability of technologies can ease the adoption process. Developers need to understand the complexities of field operations. Also, the stakeholders are advised to participate in the application development process. Technological development occurring in silos will do more harm than good. From the perspective of testing and pilot phases, experts recommend that consideration of social elements is paramount. The risk and vulnerability associated with the data of disaster victims also need to be resolved.

Governments and donors need to support capacity-building programs. Usually, donors are inclined towards funding individual disasters rather than HOs. This process prevents learning and limits the skills development process. Thus, donors need to be sensitized regarding the benefits of DSC adoption. In this context, AI-based applications and data collection tools can help improve fund allocation. Performance measurement and reporting is another critical domain of HSC, which can benefit from the digitalization process. Lastly, stakeholders are advised to integrate third-party service providers engaged in the commercial sector.

6. Conclusions and future scopes

HOs have become more favorable towards integrating digital tools and techniques in their processes and stakeholders' environment. Moreover, disruptions caused by the COVID pandemic and increased competition have compelled HOs to explore digital solutions to enhance the transparency and sustainability of their operations. HOs are constantly pursuing developing and adopting digital

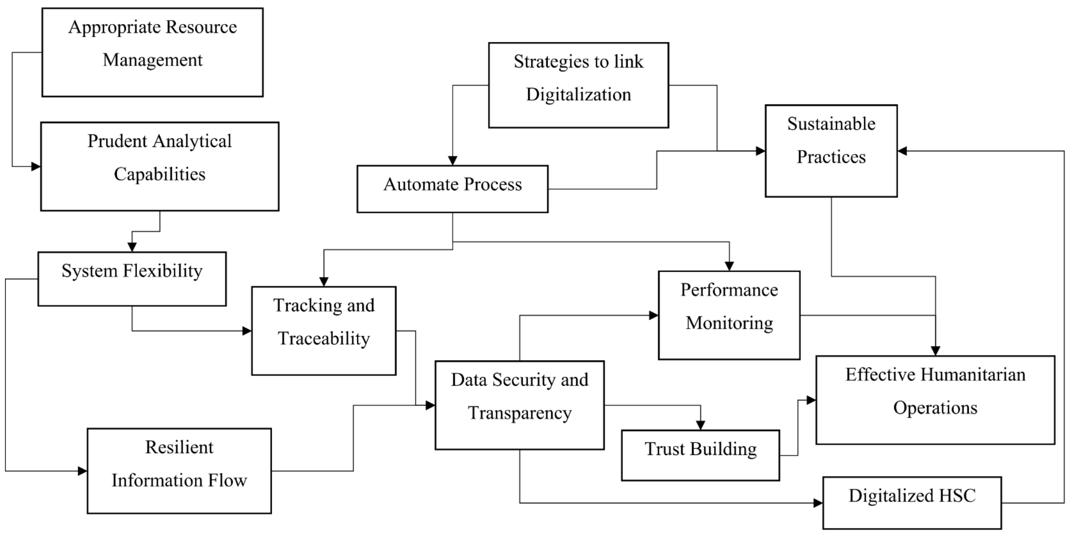

Fig. 4. Proposed framework for HSC digitalization.

tools to counter or manage the uncertainty and urgency associated with humanitarian operations. To meet those objectives, it is necessary to understand what drives digitalization and explore its dynamics to formulate suitable adoption plans.

The current study adds to the recent literature by identifying potential drivers towards digitalization in HSC and further examining the drivers to obtain cause-effect interactions adopting a neutrosophic DEMATEL approach. The present study provides interesting insights regarding the practical implications of digitalization in HSCs. Firstly, the study explored the potential objectives, motivations, processes, and impacts of digitalization. Next, literature analysis and experts' suggestions identified 19 drivers related to digitalization in the HSC. PCA was conducted to identify the potential drivers reflecting the most significant variations. Kappa analysis was conducted to place 14 drivers into four categories. Finally, the identified drivers were ranked to assist decision-makers in identifying the most influential drivers.

A cause-effect digraph was synthesized, highlighting the most appropriate point for intervention. The cause-effect digraph provides several interesting insights regarding drivers' behavior towards digitalization and their implications for HSC. This will help HSC practitioners improve operational performance by employing digital tools and techniques.

Although the comprehensive work provided in this study extracted various hidden interactions among drivers of digitalization and derived insights into the digitalization process, there were limitations in the data collection process. This study uniquely derived digitalization drivers, which had occurred earlier in silos for different technologies. The driver set can be extended when technology and applications are deployed or tested. Further, the qualitative opinion of experts from India can be observed as another limitation. Future researchers must explore the suggestions of experts from different regions in similar studies. The future studies can be extended to discover the hierarchical relationship among drivers adopting TISM methodology. In addition, the results from the neutrosophic DEMATEL can be compared with grey or fuzzy DEMATEL for future studies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is available within the article.

Appendices

Appendix A

Neutrosophic Sets and Numbers [128–130]

Definition 1. The Neutrosophic set consists of three membership functions, $T_A(x)$, $I_A(x)$ and $F_A(x)$ denotes truth, indeterminacy and falsity membership functions, respectively, where X is the universe of discourse and $T_A(x)$, $I_A(x)$, $F_A(x)$: X →] $^-0$, 1^+ [, which satisfy the condition $-0 \leq \inf T_A(x) + \inf I_A(x) + \inf F_A(x) \leq \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leq 3+$ for all x ∈ X.

Definition 2. A single value Neutrosophic Set can be expressed in the form of:

$$A = \{\langle x, T_A(x), I_A(x), F_A(x)\rangle : x \in X\} \tag{11}$$

where, $T_A(x)$,$I_A(x)$,$F_A(x)$: X → [0,1], satisfy the condition, $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$. A Single Value Neutrosophic Number can be expressed as A = (t,i,f), where t, i, f ∈ [0,1] and satisfies $0 \leq t + i + f \leq 3$.

Definition 3. A Triangular Single Value Neutrosophic Number which is denoted by $\tilde{a} = \langle (a_1, a_2, a_3); \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle$, is a neutrosophic set on ℝ, whose truth, indeterminacy and falsity membership function can be defined as:

$$T_{\tilde{a}}(x) = \begin{cases} \alpha_{\tilde{a}\left(\frac{x-a_1}{a_2-a_1}\right), a_1 \leq x \leq a_2} \\ \alpha_{\tilde{a}, x=a_2} \\ \alpha_{\tilde{a}\left(\frac{a_3-x}{a_3-a_2}\right), a_2 \leq x \leq a_3} \\ 0, otherwise \end{cases} \tag{12}$$

$$I_{\tilde{a}}(x) = \begin{cases} \frac{a_2 - x + \beta_{\tilde{a}}(x - a_1)}{a_2 - a_1}, a_1 \leq x \leq a_2 \\ \beta_{\tilde{a}}, x = a_2 \\ \frac{x - a_2 + \beta_{\tilde{a}}(a_3 - x)}{a_3 - a_2}, a_2 \leq x \leq a_3 \\ 1, otherwise \end{cases} \tag{13}$$

$$F_{\tilde{a}}(x) = \begin{cases} \frac{a_2 - x + \gamma_{\tilde{a}}(x - a_1)}{a_2 - a_1}, a_1 \le x \le a_2 \\ \gamma_{\tilde{a}}, x = a_2 \\ \frac{x - a_2 + \gamma_{\tilde{a}}(a_3 - x)}{a_3 - a_2}, a_2 \le x \le a_3 \\ 1, otherwise \end{cases} \tag{14}$$

where, $\alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \in [0,1]$, $a_1, a_2, a_3 \in \mathbb{R}$ and $a_1 \le a_2 \le a_3$.

Definition 4. The following operations can be defined if two Triangular Single Value Neutrosophic Number as $\tilde{a} = \langle (a_1, a_2, a_3)\,;\ \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle$, and $\tilde{b} = \langle (b_1, b_2, b_3)\,;\ \alpha_{\tilde{b}}, \beta_{\tilde{b}}, \gamma_{\tilde{b}} \rangle$, is given:

Addition: $\tilde{a} + \tilde{b} = \left\langle (a_1 + b_1, a_2 + b_2, a_3 + b_3)\,;\ \alpha_{\tilde{a}} \bigwedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \bigvee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \bigvee \gamma_{\tilde{b}} \right\rangle$

Subtraction: $\tilde{a} - \tilde{b} = \left\langle (a_1 - b_1, a_2 - b_2, a_3 - b_3)\,;\ \alpha_{\tilde{a}} \bigwedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \bigvee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \bigvee \gamma_{\tilde{b}} \right\rangle$

Inversion: $\tilde{a}^{-1} = \langle (a_3^{-1}, a_2^{-1}, a_1^{-1})\,;\ \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle$

Multiplication by scalar number: $\lambda\tilde{a} = \begin{cases} \langle (\lambda a_1, \lambda a_2, \lambda a_3)\,;\ \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle, \lambda > 0 \\ \langle (\lambda a_3, \lambda a_2, \lambda a_1)\,;\ \alpha_{\tilde{a}}, \beta_{\tilde{a}}, \gamma_{\tilde{a}} \rangle, \lambda < 0 \end{cases}$

Multiplication of two triangular neutrosophic numbers:

$$\tilde{a}\tilde{b} = \begin{cases} \left\langle (a_1 b_1, a_2 b_2, a_3 b_3)\,;\ \alpha_{\tilde{a}} \bigwedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \bigvee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \bigvee \gamma_{\tilde{b}} \right\rangle, a_3 > 0 \; and \; b_3 > 0 \\ \left\langle (a_1 b_3, a_2 b_2, a_3 b_1)\,;\ \alpha_{\tilde{a}} \bigwedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \bigvee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \bigvee \gamma_{\tilde{b}} \right\rangle, a_3 < 0 \; and \; b_3 > 0 \\ \left\langle (a_3 b_3, a_2 b_2, a_1 b_1)\,;\ \alpha_{\tilde{a}} \bigwedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \bigvee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \bigvee \gamma_{\tilde{b}} \right\rangle, a_3 < 0 \; and \; b_3 < 0 \end{cases}$$

Division of two triangular neutrosophic numbers:

$$\frac{\tilde{a}}{\tilde{b}} = \begin{cases} \left\langle \left(\frac{a_1}{b_1}, \frac{a_2}{b_2}, \frac{a_3}{b_3}\right)\,;\ \alpha_{\tilde{a}} \bigwedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \bigvee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \bigvee \gamma_{\tilde{b}} \right\rangle, a_3 > 0 \; and \; b_3 > 0 \\ \left\langle \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}\right)\,;\ \alpha_{\tilde{a}} \bigwedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \bigvee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \bigvee \gamma_{\tilde{b}} \right\rangle, a_3 < 0 \; and \; b_3 > 0 \\ \left\langle \left(\frac{a_3}{b_3}, \frac{a_2}{b_2}, \frac{a_1}{b_1}\right)\,;\ \alpha_{\tilde{a}} \bigwedge \alpha_{\tilde{b}}, \beta_{\tilde{a}} \bigvee \beta_{\tilde{b}}, \gamma_{\tilde{a}} \bigvee \gamma_{\tilde{b}} \right\rangle, a_3 < 0 \; and \; b_3 < 0 \end{cases}$$

where, $\wedge$ is a t-norm and $\vee$ is a t-conorm.

The triangular single value neutrosophic number can be converted into real numbers using following equations:

$$S(\tilde{a}) = \frac{1}{8}\left[a_1 + a_2 + a_3\right]\left(2 + \alpha_{\tilde{a}} - \beta_{\tilde{a}} - \gamma_{\tilde{a}}\right) \tag{15}$$

$$A(\tilde{a}) = \frac{1}{8}\left[a_1 + a_2 + a_3\right]\left(2 + \alpha_{\tilde{a}} - \beta_{\tilde{a}} + \gamma_{\tilde{a}}\right) \tag{16}$$

where, $S(\tilde{a})$ *and* $A(\tilde{a})$ are known as Score Index and Precision Index, respectively.

Appendix B

Table B1
Descriptive statistics of the data

Drivers Code	Mean	Standard deviation
D1	2.3094	1.11188
D2	3.6031	1.20161
D3	2.5250	1.24920
D4	2.0000	.95,017
D5	2.0031	.85,096
D6	2.5750	1.25221
D7	3.4563	1.23860
D8	2.9219	1.02790
D9	3.9938	.96,000
D10	3.5656	1.13732
D11	3.3375	1.19763
D12	2.9188	1.20850
D13	3.2188	.97,731

(*continued on next page*)

Table B1 (*continued*)

Drivers Code	Mean	Standard deviation
D14	2.3063	.93,014
D15	3.6125	.99,835
D16	3.6031	.98,991
D17	3.6313	1.24252
D18	3.1813	.95,918
D19	2.7094	.87,453

Table B2
The eigenvalue of each component and the proportion of the corresponding variance in the data

Component	Eigenvalues	% of variance	Cumulative %
1	2.912	15.326	15.326
2	1.582	8.328	23.654
3	1.259	6.627	30.280
4	1.190	6.264	36.544
5	1.133	5.962	42.506
6	1.059	5.573	48.079
7	1.028	5.410	53.489
8	.973	5.121	58.610
9	.935	4.919	63.529
10	.889	4.678	68.207
11	.843	4.435	72.642
12	.823	4.332	76.975
13	.761	4.003	80.978
14	.720	3.791	84.769
15	.713	3.752	88.521
16	.630	3.318	91.839
17	.622	3.272	95.111
18	.539	2.839	97.950
19	.389	2.050	100.000

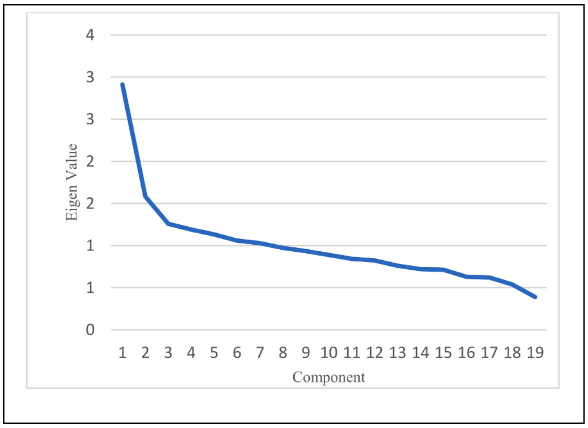

Fig. B1. Scree plot

Appendix C

Table C1
Kappa statistics and consensus of experts

Drivers	Categories				p_i
	Operational	Organizational	Technological	Social	
D2	13	2	0	0	0.752
D3	13	1	1	0	0.743
D5	2	2	1	10	0.448

(*continued on next page*)

Table C1 (*continued*)

Drivers	Categories				p_i
	Operational	Organizational	Technological	Social	
D6	0	1	14	0	0.867
D8	1	2	12	0	0.638
D9	2	0	13	0	0.752
D10	1	14	0	0	0.867
D11	14	0	0	1	0.867
D13	1	0	14	0	0.867
D15	2	12	1	0	0.638
D16	2	11	2	0	0.543
D17	1	14	0	0	0.867
D18	0	1	0	14	0.867
D19	0	0	0	15	1.000
$\mathbf{p_j}$	0.248	0.286	0.276	0.190	

Appendix D

Table D1
Pairwise comparison of drivers using neutrosophic numbers by Expert 1

	Operational	Organizational	Technological	Social
Operational	$\tilde{0}$	$\tilde{2}$	$\tilde{3}$	$\tilde{2}$
Organizational	$\tilde{2}$	$\tilde{0}$	$\tilde{1}$	$\tilde{2}$
Technological	$\tilde{3}$	$\tilde{2}$	$\tilde{0}$	$\tilde{1}$
Social	$\tilde{3}$	$\tilde{3}$	$\tilde{4}$	$\tilde{0}$

Table D2
Comparison matrix of transformed neutrosophic numbers into real numbers (Expert 1)

	Operational	Organizational	Technological	Social
Operational	0.000	2.138	3.263	2.138
Organizational	2.138	0.000	0.844	2.138
Technological	3.263	2.138	0.000	0.844
Social	3.263	3.263	4.500	0.000

Table D3
Aggregated pairwise comparison matrix for categories

	Operational	Organizational	Technological	Social
Operational	0.000	2.588	2.813	2.363
Organizational	1.103	0.428	1.879	2.588
Technological	3.533	3.038	0.900	1.361
Social	1.586	1.676	1.924	0.000

Table D4
Normalized direct relation matrix for categories

	Operational	Organizational	Technological	Social
Operational	0.000	0.293	0.318	0.268
Organizational	0.125	0.048	0.213	0.293
Technological	0.400	0.344	0.102	0.154
Social	0.180	0.190	0.218	0.000

Table D5
Total relation matrix with cause-effect relationship among categories

Categories	R	D	R + D	R-D	Cause/Effect
Operational	4.091	3.417	7.509	0.674	Cause
Organizational	3.201	4.090	7.290	−0.889	Effect

(*continued on next page*)

Table D5 (*continued*)

Categories	R	D	R + D	R-D	Cause/Effect
Technological	4.667	3.962	8.629	0.706	Cause
Social	2.946	3.438	6.384	−0.491	Effect

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