Annals of Operations Research (2019) 283:1227–1258
https://doi.org/10.1007/s10479-018-2963-3

S.I.: APPLICATIONS OF OR IN DISASTER RELIEF OPERATIONS, PART II

Modelling the inter-relationship between factors affecting coordination in a humanitarian supply chain: a case of Chennai flood relief

Lijo John[1] · Anand Gurumurthy[1] · Gunjan Soni[2] · Vipul Jain[3]

Published online: 16 July 2018

Abstract

The humanitarian supply chain (HSC) aims at providing relief to affected people in the wake of a disaster at the right place and at the right time to reduce their suffering. One of the major challenges faced by the HSC is the coordination between various actors. Previous studies have identified the factors affecting coordination but the literature is silent on the inter-dependence between these factors (criteria). In this study, we identify the factors affecting coordination based on the review of extant literature in HSC and interviews with multiple individuals representing various stakeholders involved with the relief activities carried out during the Chennai floods. These factors were grouped into four categories: information sharing, diversity (of the humanitarian agencies), organizational mandates and material convergence. We use a hybrid fuzzy DEMATEL-ANP methodology to identify the interdependence and develop the network relationship diagram by mapping the interdependence between the factors affecting the effective coordination between the actors in HSC. Our results indicate that information exchange between the humanitarian actors (HA) tantamount to achieve coordination in post disaster response phase. However, with the improvement in the post–disaster coordination, the HAs need to focus on pre-disaster preparedness phase through strong alignment of organizational mandates of HAs and focus on the diverse nature of HAs to align their operational strategies through standardized operations, inter-operability of activities and building trust through long term associations.

Keywords Disaster management · Humanitarian supply chain · Fuzzy · DEMATEL · ANP · Coordination · Floods · Chennai

✉ Vipul Jain
Vipul.Jain@vuw.ac.nz

Extended author information available on the last page of the article

1 Introduction

Humanitarian Supply Chain (HSC) aims to reduce the impact of the disaster on the lives of the affected people and rehabilitate the affected people to a better condition. The complex operating conditions of HSC warrants a coordinated effort of multiple stakeholders such as humanitarian aid agencies, local government, national and international Non-Government Organisations (NGOs), military, donors, affected people, etc. However, coordination between multiple stakeholders has been a major concern in the HSC operations (Van Wassenhove 2006). Poor coordination between the stakeholders in HSC has led to the loss of lives, increased operating cost, wastage of resources and poor aid distribution. Though the need for coordination between the stakeholders has been well recognized in HSC, it still continues to be a fundamental weakness of the humanitarian actions (Balcik et al. 2010).

Unlike commercial supply chain, HSC operates under disrupted, dynamic and often politically charged environment (Olaogbebikan and Oloruntoba 2017). For instance, during the cyclone Nargis in Myanmar (2008), the military refused to allow certain countries to carry out the relief activities. Hence, the French and U.S. ships with aid supplies were anchored just offshore for more than 2 weeks before finally leaving (Day et al. 2012). Apart from this, the most important distinction from the commercial supply chain is the objective function of the HSC, which is to minimise “the suffering brought about by the lack of goods and services” (Holguín-Veras et al. 2012, p. 498). The direct impact of the disasters on the lives of the affected population can be reduced through long-term strategic planning during the mitigation and preparedness phase. Despite the planning, the effectiveness of the post-disaster relief activities can be affected due to ineffective management and poor coordination (Balcik et al. 2010).

1.1 Impact of poor coordination

Lack of poor coordination between the humanitarian actors often result in increased suffering, overlapping and duplication of relief activities (Jahre and Jensen 2010), increased cost of operations (Van Wassenhove 2006; Jabbour et al. 2017), slow and inequitable distribution of aid materials (Dubey et al. 2017). According to Global Assessment Report (2015) the funding for the humanitarian operations has increased by 9% between 2009 and 2014, while during the same period, the amount of unmet demand rose by 22%. The report identifies that one of the prime reason for this increase in the gap between demand and supply is due to poor coordination between the various agencies leading to wastage of resources. During the post Indian Ocean tsunami, nearly 5000 large and small NGO’s were operating in Indonesia alone, with no central authority and leading to huge pressure and competition for already scarce resources (Chia 2007). Also after 6 months of Indian Ocean tsunami, nearly 2000 tons of aid materials were lying in Djakarta airport utilizing the space with no one to claim the aid (Telford 2006). On another instance, owing to poor inter-agency coordination after Pakistan earthquake (2005), a certain minority tribe was completely ignored for over 10 days after the disaster took place and no relief and aid material arrived until almost 2 weeks after the earthquake.

Complex and chaotic operational environment does not necessarily encourage coordination in HSC and it often becomes challenging owing to multiple reasons. For instance, the HAs involved in the relief activities repeatedly have conflicting and competing mandates owing to geographical, cultural and organisational policies impeading coordination between these entities (Van Wassenhove 2006). With no central authority, the relief environment is often unregulated in nature, and to initiate other agencies to engage in coordinated activities (Anaya-Arenas et al. 2014). Furthermore, the relief efforts often rely upon the donor organization for providing the relief goods and services. Though HSC managers make requests, the aid received often depend upon the availability of material with the donors (Day et al. 2012). Additionally, HSC functions under high levels of uncertainty regarding the timing and location of disaster, beneficiary requirements, donations, infrastructure, and even relief group membership (Van Wassenhove 2006). Complexity in HSC coordination also arises due to an influx of a large number of individuals, groups or organizations attempting to help in the disaster relief mission (Stephenson 2005). The uncertainty associated with the disaster and the impending lack of resources (financial, technological and informational) coupled with short-term volunteers often makes any pre-disaster coordination strategies ineffective.

1.2 Motivation

Banomyong et al. (2017) in their systematic review of the humanitarian literature identified that empirical methodologies such as case studies and survey methodologies need to be increasingly used in humanitarian research. Previous studies have used multiple case studies such as Tohoku earthquake (Holguín-Veras et al. 2014), Haitian earthquake (Yates and Paquette 2011), Hurricane Katrina (Comfort 2007), etc. and identified that the coordination between the actors was particularly a painful affair. Though the previous studies have explored the coordination challenges and have identified a multitude of the factors affecting coordination, these studies have not explored the interactions and interdependence of these factors. However, it becomes imperative for the practitioners to understand the causal and logical relationship between the factors affecting coordination and should not be considered in a standalone fashion since it can lead to a difference between life and death of the affected person. We use the Chennai floods as the case in this study for exploring the factors affecting coordination and their interactions in HSC. Chennai flood offers both the scale and magnitude of a large-scale disaster and the coordination challenges observed during the relief activities post Chennai floods was not an isolated event. Therefore, the objectives of this study are:

- To identify various factors affecting coordination in HSC.
- To rank these factors in the order of their importance on the effect on coordination.
- To empirically validate the interactions and interdependence between the factors affecting coordination.

Defining the inter-dependence between factors affecting the coordination in HSC requires an evaluation of interaction at criteria and sub-criteria levels. To evaluate complex interactions, sophisticated techniques are required. Some of the common methods to evaluate such structural dependencies (Gölcük and Baykasoglu 2016) include Analytic Hierarchy Process (AHP) (Saaty 1980), Analytic Network Process (ANP) (Saaty 1996), Technique for Order Preference by Similarity to Ideal Situation (TOPSIS) (Hwang and Yoon 1981), etc. However, these methodologies assume a pre-defined structural relationship existing among the interacting criteria. In many real-world cases, the complex nature of the problem prevents the understanding of interactions between the criteria in a simplistic manner, warranting a systematic evaluation of these interactions. Decision Making Trial and Evaluation Laboratory (DEMATEL) provides a robust methodology for identifying these interactions at a causal level (Gabus and Fontela 1973). The hybridization of several techniques with DEMATEL is common. Hybrid technique of DEMATEL and ANP provides opportunities for exploring the inter-dependence and identifying the importance of each criterion in a complex phenomenon.

The rest of the paper is organised as follows. In Sect. 2, we present the review of the relevant literature and identify the factors affecting the coordination in HSC and in Sect. 3, a detailed exposition into the methodology is provided. In Sect. 4, all the relevant facts relating to the case - the Chennai floods is provided. In Sects. 5 and 6, we present the data analysis and discussion respectively. Section 7 concludes the paper.

2 Literature review

This section is divided into two sections. The first section reviews the humanitarian literature to explore the various factors affecting the coordination between the humanitarian actors, while the second section would focus on previous studies on the application of multi-criteria decision making (MCDM) methods modelling both the interaction and interdependence.

2.1 Factors affecting coordination in HSC

2.1.1 Information sharing between the humanitarian agencies (IS)

The information sharing between HAs during the HSC operations is paramount for saving lives of the affected people due to the disaster (Day et al. 2012). Often humanitarian practitioners require information regarding the intensity of disaster impact, size of affected population, location, nature of aid material required, etc. for planning relief activities (Hossain and Uddin 2012). However, in the post-disaster chaotic conditions, the inter-agency information sharing does not become a priority and often leading to duplication of efforts and wastage of valuable resources (Leiras et al. 2014; Ergun et al. 2014; Anaya-Arenas et al. 2014). The poor information exchange between humanitarian agencies is due to lack of effective mechanisms for information exchange owing to the lower priority for designing inter-agency information exchange in the pre-disaster preparedness phases (Kent 2004). Even though the international agencies such as Office of Coordination of Humanitarian Affairs (OCHA), United Nations High Commissioner for Refugees (UNHCR), Federal Emergency Management Agency (FEMA) has increasingly adopted the use of technology to facilitate coordination, these organizations often do not include smaller and local level agencies in the preparedness phase. Such exclusions often lead to loss of valuable local information—specifically the socio-economic and cultural information regarding the affected community (Balcik et al. 2010).

Lack of uniform need assessment techniques also leads to varied estimates of the relief requirements. Moreover, each agency collects and processes data based on their capabilities and operating mandates. This lead to multiple data formats. The lack of consistent data formats also makes inter-agency information sharing and processing inefficient and ineffective (Seybolt 2009). The agencies seldom arrive at a consensus regarding the need assessment (Altay and Labonte 2014). One of the primary reasons for the ineffective information sharing is due to lack of focus on the collection and consolidation of information in the pre-disaster stage. The agencies rarely collaborate during the preparedness phase of the disaster management leaving the relief phase coordination strategies unformulated. This poor planning for coordination prior to relief operations impedes the information sharing (Van Wassenhove 2006). Poor information sharing between the agencies distorts the actual need of the beneficiaries in many cases and affects the relief operations (Sheppard et al. 2013).

2.1.2 Material convergence (MC)

In the aftermath of a disaster, donors send a massive amount of supplies to the disaster site. Material convergence can be understood as the excessive convergence of the supplies and equipment at the disaster site sent by all of the entities that respond to a disaster, including governments, relief agencies, companies, religious entities, local community groups and individuals (Holguín-Veras et al. 2012). Beginning with Fritz and Mathewson (1957) to the recent Haitian earthquake, multiple authors have recorded the impact of material convergence on the humanitarian relief activities and the coordination between agencies. These items create inventory management issues and are often called as second-tier disaster (Holguín-Veras et al. 2012). The unusable and unsolicited aid material consume valuable time of the volunteers in managing these materials, all the while when they could be used for more essential tasks. This chaotic operating environment often leads to conflict, confusion, and congestion thereby affecting coordination between the HAs at or near the disaster site (Fritz and Mathewson 1957).

A typically overlooked factor in the material convergence is the heterogeneous nature of the aid received including non-priority items and even potentially dangerous items such as drugs past their expiry dates (Holguín-Veras et al. 2012). Frequently, the logisticians encounter with the scarcity of critical items while having an abundance of unwanted material. This scarcity often leads to competition among the humanitarian agencies for receiving the scarce critical aid material from the pile of unwanted donations and affect the coordination between the various actors (Altay and Pal 2014). Furthermore, scarcity of the experienced logistics providers and safe location for setting up of last mile distribution centres leads to a loss in transit and pillage of the aid material. However, as the situations stabilize, a large influx of aid from various donors arrives at the disaster site (Balcik et al. 2010). Consequentially, the abundance of the aid often intensifies the wastage and mismanagement through improper poor stock keeping of the inbound aid material. The poor resource utilization does not stand well with the donors requiring accountability (Davis et al. 2013) and often tightening donations of the high priority items and further intensifying competition between the agencies for receiving donations (Stephenson 2005; Gonzalez 2010).

2.1.3 Diversity of actors in HSC (DA)

HSC, not only has to deal with the convergence of the material but also the convergence of a large number of organizations. In a post-disaster scenario, large numbers of volunteers, agencies, and stakeholders respond to disaster by being a part of rescue and relief operations. For instance, during the Indian Ocean tsunami, more than 5000 NGOs were involved in relief activities (Van Wassenhove 2006). The humanitarian actors involved in the relief operations come from a diverse background with multiple objectives and mandates (Apte 2009). The humanitarian actors often lack prior experience in handling a disaster situation and tend to overlook the importance of coordination with other stakeholders (Zetter 1995; Tatham and Spens 2011).

Though it is expected that the organizations would focus on coordination, formal associations for coordination between the agencies are not common in practice (Tomasini and van Wassenhove 2009). Since the HSC operates in the chaotic environment with host government, military, local and international NGOs, private companies etc., converging at the same location, the coordination between the actors demands rapid trust building (Tatham and Kovács 2010; Heaslip et al. 2012). Trust is usually developed through long-term association and personal relationships. Even though there might not be any formal association between the humanitarian agencies due to their diverse nature of specialization, funding patterns, donor expectations, etc., informal agreements based on personal relationships help form coordination (Dubey et al. 2017; Moshtari 2016). However, owing to a limited number of experienced logisticians and high churn rate, any informal arrangement is short-lived affecting HSC coordination and effectiveness of relief operations (Day et al. 2012; Schulz and Blecken 2010).

2.1.4 Conflicting organizational mandates (OM)

The agencies and stakeholders that participate in the HSC activities have varied organizational mandates defining their operating philosophy, source and nature of funding, type and duration and extent of association with the affected people, etc. (Kamradt-Scott 2016). Usually, a HA specializes in a limited range of activities in disaster management such as camp management, medical care or water and sanitation (Jahre and Jensen 2010). However, irrespective of their specialization, these agencies tend to participate in all stages of disaster management. This affects the effectiveness of relief operations and thereby the coordination between the agencies (Schulz and Blecken 2010; Tomasini and van Wassenhove 2009).

Each agency also might have a specific set of interests and socio-economic and political affiliations (Stephenson 2005). Humanitarian agencies often operate solely on the donations and hence both aid recipients and the donors are considered as "customers" (Van Wassenhove 2006; Oloruntoba 2005). The humanitarian agencies are required to cater to the donor requirements as well as the beneficiary requirements. Often these requirements conflict with each other and hamper the coordination (Ertem et al. 2012).

Usually, when large independent humanitarian agencies with their own funding mechanisms combine operation with local specialized humanitarian agencies, they face a series of challenges in coordination as observed during Darfur crisis and Indian Ocean tsunami (Adinolfi et al. 2005). These cases indicate the need for coordination based preparedness activities focusing on contingency planning, needs assessment, appeals, transport management and last-mile distribution (Oloruntoba 2005).

Based on the synthesis of the literature, the various criteria, and sub-criteria affecting the coordination in HSC are summarized in Table 1.

2.2 Multi criteria decision making

Literature provides numerous examples of the application of various MCDM methods, either individually or in combination with other methods, both in conventional form and in a fuzzy environment. Kayikci (2010), Li et al. (2011) and Tuzkaya and Gülsün (2008) employed MCDM methodologies in the selection of the logistics providers, while, Datta et al. (2013) and Gupta et al. (2012) used MCDM methodologies for the selection of suppliers. He et al. (2012) addressed the trans-shipment problems in logistics research as a MCDM problem, whereas Haleh and Hamidi (2011) have studied allocation of orders to suppliers while logistics network design. Design of distribution channels for the logistics providers (Paksoy et al. 2012) and ranking studies (Sawicka and Zak 2014) also employed MCDM methodologies. However, the use of these methods in HSC research is still not explored to a great extent. Moreover, the nature of the coordination problem in HSC provides an ideal setting for the usage of the hybrid DEMATEL-ANP methodology for exploring the interaction between the factors affecting the HSC coordination and to identify the importance of each factor.

Table 1 Criteria and sub-criteria that affects coordination in HSC

Criteria	Sub-criteria	References
Information sharing (IS)	Low priority for information sharing (IS1)	Leiras et al. (2014), Ergun et al. (2014), Anaya-Arenas et al. (2014)
	Lack of knowledge about the requirement of beneficiaries (IS2)	Seybolt (2009)
	Poor planning for coordination prior to relief operations (IS3)	Van Wassenhove (2006)
	Lack of uniform need assessment techniques (IS4)	Seybolt (2009), Altay and Labonte (2014)
	Lack of consistent data formats being shared among agencies (IS5)	Sheppard et al. (2013), Balcik et al. (2010)
Material convergence (MC)	Use of personnel for less essential task (MC1)	Balcik et al. (2010), Davis et al. (2013)
	Competition between agencies for scarce resources (MC2)	Balcik et al. (2010), Stephenson (2005), Gonzalez (2010)
	Heterogeneous nature of aid material received (MC3)	Holguín-Veras et al. (2012), Altay and Pal (2014)
	Receiving large quantities of non-priority items (MC4)	Fritz and Mathewson (1957), Holguín-Veras et al. (2012), Van Wassenhove (2006)
	Scarcity and oversupply of aid materials (MC5)	Balcik et al. (2010), Gonzalez (2010)
Diversity of actors (DA)	Coordination based on the reputation of official (DA1)	Tomasini and van Wassenhove (2009)
	Diverse nature of interacting agencies (DA2)	Apta (2009), Van Wassenhove (2006)
	Large number of actors (DA3)	Day et al. (2012), Schulz and Blecken (2010)
	Lack of trust among interacting agencies (DA4)	Dubey et al. (2017), Moshtari (2016)
Organizational mandates (OM)	Divergent set of interest for interacting agencies (OM1)	Kamradt-Scott (2016)
	Varying donor expectation from relief operations (OM2)	Stephenson (2005), Oloruntoba (2005)
	Varying specialization of interacting agencies (OM3)	Jahre and Jensen (2010), Schulz and Blecken (2010), Tomasini and van Wassenhove (2009)
	Lack of preparedness for coordination between agencies (OM4)	Oloruntoba (2005), Balcik et al. (2010)

In previous years, multiple applications of DEMATEL with ANP have been used to map and identify “cause and effect” relationship in under various occasions. Furthermore, multiple variants of the hybrid models are seen in the literature. One such variant is Inner Dependency of ANP (IDANP) as defined by Gölcük and Baykasoglu (2016). ANP manages both inner and outer dependencies, where inner dependency refers to “within the cluster” and outer dependency refers to the “dependencies between the clusters”. In majority of the DEMATEL-ANP hybridization, DEMATEL is primarily used for identifing the Network Relationship Map (NRM). Such problem structure require a large number of pairwise comparisons, for establishing the weighted super matrix and identification of the network relationships. However, IDANP approach utilizes the super matrix from DEMATEL for capturing inner dependencies. This approach overcomes two major shortcomings of ANP (Büyüközkan and Çifçi 2012). Firstly, ANP requires large number of pairwise comparison which might be time consuming and often difficult to obtain. Secondly, for certain situations, pairwise comparison might become difficult to interpret especially for the inner dependencies. Previous studies have also used IDANP approach for DEMATEL-ANP hybridization. For instance, Wu (2008) used ANP-DEMATEL hybridization for selecting knowledge management strategies in a Taiwanese company by obtaining the inner dependency matrix from DEMATEL. Shen et al. (2011) proposed an integrated methodology for capturing the inner dependency using the DEMATEL among the criteria for a technology selection model. Tseng (2011) proposed a hybrid framework for measuring environmental knowledge management capability where the inner dependency matrix was obtained from DEMATEL which was subsequently used to arrive at the steady state matrix. Tseng (2009) used DEMATEL to capture the cause and effect between criteria by structuring the criteria as a single cluster and handling the inner dependency through DEMATEL. Büyüközkan and Çifçi (2012) used a hybrid fuzzy DEMATEL ANP and TOPSIS methodology to evaluate the green supplier where the inner dependency was handled by the fuzzy DEMATEL and the obtained unweighted super matrix was completed in conjunction with the fuzzy ANP pairwise comparison. Büyüközkan and Öztürkcan (2010) used a hybrid method to aid companies prioritize Six Sigma projects where the inner dependencies were obtained through DEMATEL and the unweighted super matrix was raised to sufficient power to obtain the steady state matrix.

Similar to the above papers, the current problem setting too requires identification of relationship between the variables at two levels. The first is at criteria level and second at the sub-criteria level. In particular, it requires identifying causal dependency between both criteria and sub-criteria. Hence, DEMATEL method is used for clarifying inter-dependence between the criteria affecting HSC coordination, while ANP is used to measure the relative importance of these criteria affecting the HSC coordination. The nature of the current problem also requires the calculation of both outer and inner dependencies between criteria and sub-criteria prior to the calculation of the weights. The DEMATEL method provides the NRM required for the ANP to calculate the initial super matrix. Furthermore, fuzzy methodology has been used in this context since it offers capability to effectively capture the subjectivity in decision maker’s perception of the situation. Fuzzy logic is applied in the situation where understanding is quite judgmental and the process where human reasoning and decision making is involves complexities, as in the case of HSC (Deb et al. 2002).

Table 2 Linguistic scales for the importance weight of criteria

Linguistic variables	Corresponding TFN
No influence	(0, 0.1, 0.3)
Low influence	(0.1, 0.3, 0.5)
Medium influence	(0.3, 0.5, 0.7)
High influence	(0.5, 0.7, 0.9)
Extreme influence	(0.7, 0.9, 1.0)

3 Methodology

DEMATEL was developed at Geneva Research Centre of Battelle Memorial Institute (Gabus and Fontela 1973) to pragmatically visualize the structure of complicated causal relationships. Although, DEMATEL provides the causal relationships by giving crisp values defining the strength of the relationships, often in real life the relationships are subjective. To capture this subjectivity in the relationships fuzzy set theory has been used.

Design the fuzzy linguistic scale: The first step in employing a fuzzy DEMATEL methodology is to design the fuzzy linguistic scale. To capture the ambiguities of assessments, the linguistic variable "influence" is used with five linguistic terms, namely {No Influence, Low Influence, Medium Influence, High Influence, Extreme Influence}, that are expressed in positive triangular fuzzy numbers (l_{ij}, m_{ij}, h_{ij}), as shown in Table 2 (Opricovic and Tzeng 2004).

Calculate the fuzzy direct-influence matrix: The scores depend on the views of the experts on the pair wise comparison for the factors in Table 1. Based on Table 2, convert the numerical relationship between the factors in Table 1 into the fuzzy direct-influence matrix $\tilde{D}$ according to the fuzzy linguistic conversion (Chen et al. 2011).

$$\tilde{D} = \left[\tilde{d}_{ij}\right]_{nxn}, \quad where\ \tilde{d}_{ij} = \left(d_{ij}^{l}, d_{ij}^{m}, d_{ij}^{h}\right). \tag{1}$$

Normalize the fuzzy direct-influence matrix: The fuzzy direct-influence matrix $\tilde{D}$, is normalized to get the fuzzy direct-relation matrix $\tilde{N}$ by the relation given as (Chen et al. 2011):

$$\tilde{N} = \frac{\tilde{D}}{u}, \quad where\ u = max_{ij}\left(max_i \sum_{j=1}^{n} d_{ij}, max_j \sum_{i=1}^{n} d_{ij},\right), i, j \in \{1, 2, \ldots, n\} \tag{2}$$

$\tilde{N} = \left[\tilde{e}_{ij}\right]_{nxn}, \tilde{e}_{ij} = (e_{ij}^{l}, e_{ij}^{m}, e_{ij}^{h})$, where n is the total numb of elements.

Attain the fuzzy total-influence matrix: Once the normalized fuzzy direct-influence matrix $\tilde{N} = (N^l, N^m, N^h)$ is obtained, where $N^l = \left[e_{ij}^{l}\right]_{n\times n}, N^m = \left[e_{ij}^{m}\right]_{n\times n}$ and $N^h = \left[e_{ij}^{h}\right]_{n\times n}$. The fuzzy total-influence matrix $\tilde{T}_E = \left[\tilde{t}_{ij}\right]_{nxn},\ where\ \tilde{t}_{ij} = \left(t_{ij}^{l}, t_{ij}^{m}, t_{ij}^{h}\right)$, can be obtained by (Chang et al. 2011)

$$T_E^l = \left[t_{ij}^{l}\right]_{n\times n} = N^l\left(I - N^l\right)^{-1} \tag{3}$$

$$T_E^m = \left[t_{ij}^{m}\right]_{n\times n} = N^m\left(I - N^m\right)^{-1} \tag{4}$$

$$T_E^h = \left[t_{ij}^{h}\right]_{n\times n} = N^h\left(I - N^h\right)^{-1}. \tag{5}$$

Defuzzify into the crisp values: Using the algorithm for Converting Fuzzy data into Crisp Scores (CFCS) (shown in Sect. 3.1), the total fuzzy influence matrix $\tilde{T}_E = \left[\tilde{t}_{ij}\right]_{n\times n}$ is defuzzified into crisp values and these values are fed into the total influence matrix $T_E = \left[t_{ij}^E\right]_{n\times n}$ (Zhou et al. 2011).

Once the defuzzified total influence matrix T_E, is calculated, the sum of the row and column values for T_E is obtained. A sum of the column values implies the overall influence of other factors on a given factor. Sum of column values of T_E denoted by D, is formally expressed as

$$D = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1}, \quad (i = 1, 2, \ldots, n). \tag{6}$$

Sum of the row values implies the overall influence of a given factor on other factors. In addition to sum of column values of T_E, the sum of row values of T_E, denoted by R, can be calculated as

$$R = \left[\sum_{i=1}^{n} t_{ij}\right]_{n\times 1}, \quad (j = 1, 2, \ldots, n). \tag{7}$$

Set up a threshold value to obtain the causal diagram: The total-influence matrix T_E provides the information on the effect of one criterion on another. However, since not all effects are significant, the decision maker is left to choose an appropriate cut off value to filter out negligible relationships. The values in the total influence matrix which are above the cut off value are used for identifying the relationship in the NRM. The NRM can be obtained from the dataset of $(R+D, R-D)$, where the $(R+D)$ shows the horizontal axis and the $(R-D)$ shows the vertical axis.

3.1 Converting fuzzy data into crisp scores (CFCS) defuzzification method

This algorithm is based on the procedure of determining the fuzzy min and fuzzy max. The total score is determined as a weighted average according to the membership functions (Chen and Chen 2010). Let $\tilde{z}_{ij} = \left(l_{ij}, m_{ij}, h_{ij}\right)$ indicate the fuzzy assessment with regard to the degree to which the criterion 'i' affects the criterion 'j', and then the CFCS algorithm can be described in the following steps:

Step 1: *Normalization*

Calculate,

$$xl_{ij} = \frac{l_{ij} - minl_{ij}}{\Delta_{min}^{max}} \tag{8}$$

$$xm_{ij} = \frac{m_{ij} - minm_{ij}}{\Delta_{min}^{max}} \tag{9}$$

$$xh_{ij} = \frac{h_{ij} - minh_{ij}}{\Delta_{min}^{max}} \tag{10}$$

where

$$\Delta_{min}^{max} = maxh_{ij} - minl_{ij} \tag{11}$$

Step 2: *Compute the low* (*ls*) *and high* (*hs*) *of the normalized values*

$$xls_{ij} = \frac{xm_{ij}}{1 + xm_{ij} - xl_{ij}} \tag{12}$$

$$xhs_{ij} = \frac{xh_{ij}}{1 + xh_{ij} - xm_{ij}} \tag{13}$$

Step 3: *Compute the total normalized crisp values*

$$x_{ij} = \frac{\left[xls_{ij}\left(1 - xls_{ij}\right) + xhs_{ij}xhs_{ij}\right]}{\left[1 - xls_{ij} + xhs_{ij}\right]} \tag{14}$$

Step 4: *Compute the crisp values*

$$z_{ij} = minl_{ij} + x_{ij}\Delta_{min}^{max} \tag{15}$$

3.2 Linking DEMATEL and ANP

The total influence matrix obtained from DEMATEL method can be used as the inner dependency matrix in super matrix without using Saaty's pairwise comparison (Gölcük and Baykasoglu 2016). The total influence matrix is obtained from DEMATEL method is given by:

$$T_E = \begin{bmatrix} t_{11}^E & \ldots & t_{1j}^E & \ldots & t_{1n}^E \\ \vdots & & \vdots & & \vdots \\ t_{i1}^E & \ldots & t_{ij}^E & \ldots & t_{in}^E \\ \vdots & & \vdots & & \vdots \\ t_{n1}^E & \ldots & t_{nj}^E & \ldots & t_{nn}^E \end{bmatrix} \tag{16}$$

where T_E denotes the total influence matrix for inner dependency, and t_{ij}^E represents the degree of influence that the criterion i exerts on the criterion j. The influence matrix is normalized and then transposed. For normalization, the row sums are calculated as given below

$$\boldsymbol{T}_E = \begin{bmatrix} t_{11}^E \cdots t_{1j}^E \cdots t_{1n}^E \\ \vdots \\ t_{i1}^E \cdots t_{ij}^E \cdots t_{in}^E \\ \vdots \\ t_{n1}^E \cdots t_{nj}^E \cdots t_{nm}^E \end{bmatrix} \begin{matrix} \to d_1 = \sum_{j=1}^{n} t_{1j}^E \\ \\ \to d_i = \sum_{j=1}^{n} t_{ij}^E \\ \\ \to d_n = \sum_{j=1}^{n} t_{nj}^E \end{matrix} \tag{17}$$

where d_i represents the row sum value of the ith row. Each element of the total relation matrix T_E is divided by the corresponding row sums as

$$T_E^{\alpha} = \begin{bmatrix} t_{11}^E/d_1 & \dots & t_{1j}^E/d_1 & \dots & t_{1n}^E/d_1 \\ \vdots & & \vdots & & \vdots \\ t_{i1}^E/d_i & \dots & t_{ij}^E/d_i & \dots & t_{in}^E/d_i \\ \vdots & & \vdots & & \vdots \\ t_{n1}^E/d_n & \dots & t_{nj}^E/d_n & \dots & t_{nn}^E/d_n \end{bmatrix} \tag{18}$$

$$= \begin{bmatrix} t_{11}^{\alpha E} & \dots & t_{1j}^{\alpha E} & \dots & t_{1n}^{\alpha E} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{\alpha E} & \dots & t_{ij}^{\alpha E} & \dots & t_{in}^{\alpha E} \\ \vdots & & \vdots & & \vdots \\ t_{n1}^{\alpha E} & \dots & t_{nj}^{\alpha E} & \dots & t_{nn}^{\alpha E} \end{bmatrix} \tag{19}$$

where T_E^{α} represents the normalized total relation matrix for inner dependency. Finally transpose of the T_E^{α} is obtained as

$$(T_E^{\alpha})' = \begin{bmatrix} t_{11}^{\alpha E} & \dots & t_{i1}^{\alpha E} & \dots & t_{n1}^{\alpha E} \\ \vdots & & \vdots & & \vdots \\ t_{1j}^{\alpha E} & \dots & t_{ij}^{\alpha E} & \dots & t_{nj}^{\alpha E} \\ \vdots & & \vdots & & \vdots \\ t_{1n}^{\alpha E} & \dots & t_{in}^{\alpha E} & \dots & t_{nn}^{\alpha E} \end{bmatrix} \tag{20}$$

Once $\left(T_E^{\alpha}\right)'$ is obtained, it can be put into the appropriate places in supermatrix.

3.3 Analytic network process

Super matrix formulation: Based on the causal relations relationships obtained by DEMATEL, the super matrix is restructured. The dependence relationship is studied, and all the relationships found to be insignificant in the NRM obtained from DEMATEL is reduced to a value of zero in the super matrix (Chen and Chen 2010).

Final priorities of the criterion and sub-criterion: Once the unweighted super matrix is constructed, it is transformed into the weighted super matrix where the column sums unity.

Calculation of limit super matrix: The limit super matrix is calculated by

$$L = lim_{K\to\infty} W^K \tag{21}$$

where W^K is weighted super matrix and K is a large number. The limit super matrix is obtained when the rows in the matrix stabilize.

4 Chennai floods: the case study

The retreating north-east monsoon arrived at the coastal states of south India during the third week of October, 2015. Through the first week of November, 2015 a low pressure area consolidated into a depression and further intensified into deep depression. While crossing over the land mass of south India, the interaction weakened the system into a low pressure leading to very heavy rainfalls over Tamil Nadu.[1] During this period, Chennai received a rainfall of more than 483 mm in a span of two days (November 9 and 10, 2015) which lead to flooding of the low lying areas in the city. Though the first bout of rainfalls had subdued by 24th, November, 2015, another low pressure system began to develop in the Bay of Bengal by 29th, November, 2015 and the second bout of the heavy rainfalls started on 1st of December, 2015.[2] The authorities feared that the Chembarambakkam reservoir (one of the two rain fed reservoir systems which supplies water to the city of Chennai and adjacent areas) might not be able to hold the water and opened the reservoir gates without adequate warning and enough time for evacuation of residents. An estimated total of 50,000 cusec of water was released into the Cooum River, Adyar River and Buckingham Canal. It was expected that the excess water would drain off to the Bay of Bengal. However, since the periodic desilting of these rivers was not carried out as part of poor flood preparedness activities, the natural flow of water to the bay was restricted leading to the flooding of the banks of the river. The flooding of these areas was also due to the illegal encroachments of the city's natural water bodies, unplanned construction and poor flood control measures and preparedness.[3] On 2nd December, 2015, the state of Tamil Nadu declared the situation as a "national disaster". By this time nearly 40% of the city was under water and all modes of connectivity including telecommunication lines, roads and railways were disrupted. Indian railways cancelled all trains through, to and from Chennai until the situation became normal.[4]

The affected people were the first responders. There were a large number of volunteers; NGO's and local people who took part in the relief activities. However, the relief activities were largely uncoordinated with the authorities having little or no strategic plan in place. After declaring the situation as a "national disaster", 20 teams of National Disaster Relief Force (NDRF) arrived at Chennai and took over the rescue and relief activities.[5] Subsequently, the relief activities were spearheaded by the Indian Army along with Southern Command of Indian Navy and Indian Air Force. The Indian Navy used mechanized boats and rafters to access various areas to search and rescue people, while people stranded on roof tops were air lifted using helicopter with the help of Indian Air Force.[6]

The rescue activities were mostly wound up by 6th December, 2015 and the focus shifted to relief activities. More than 6000 relief shelters were operational at various places in and around Chennai. Most of the schools, colleges, community halls, and even some of the shopping malls were also converted to relief shelters. The National Crisis Management Committee (NCMC) mobilized 5000 litres of milk, 100,000 water bottles, 7 tons of biscuit and 10 tons of instant noodles to Chennai. Large amounts of relief material arrived in Chennai from various parts of the country and abroad as well. Various countries such as China, Canada, Bangladesh, France, Spain, Singapore, Japan, USA, etc. sent both relief material and cash donation for rehabilitation of the affected people in Chennai floods. Various international agencies such as International Federation of Red Cross (IFRC), United Nations Develop-

[1] Janardhanan, Arun (2 December 2015b). "Chennai drowns in deluge of water; flight services suspended". The Indian Express.

[2] Ibid.

[3] Rajendran D. and Ramanathan S. (2015) Chennai floods: What happened at Chembarambakkam, negligence or nature's fury? The News Minute (Retrieved on 9 December, 2015).

[4] "As sky turns menacing again, rescue efforts intensified". The Hindu. 5 December 2015.

[5] "Navy rushes amphibious ship to Chennai for relief ops". The Hindu. 3 December 2015.

[6] "Chennai floods: Centre sends 17 tonnes of snacks, 5000 litres milk to Tamil Nadu". The Indian Express. 4 December 2015.

ment Program (UNDP), United Nations, World Vision etc. had mobilized relief material and participated in both relief and rescue activities. Many parts of the city, especially those inhabited by the poor and socio-economically backward communities were marginalized and relief did not reach them due to the poorly coordinated relief activities. Numerous complaints were filed against the government of Tamil Nadu alleging their inability to coordinate the relief activities which had led to the loss of lives of many. Public interest litigation (PIL) was filed against the Government of Tamil Nadu in Chennai High Court seeking explanation from the government on poor coordination during the relief activities. The PIL was subsequently converted to a *suo moto* proceeding. This served also as the motivation for this research and to propose a model to understand the factors that affected the coordination during large scale disaster relief activities anchored on the Chennai floods relief program.

5 Data collection and application of the proposed methodology

The data for this study was collected using a multi-prong approach based on in-depth interviews with the key members in the relief efforts, review of multiple secondary databases such as news articles and reports published by governmental and non-governmental agencies. The interviews were conducted during visits to Chennai, Puducherry, Cuddalore and nearby areas which were significantly affected by the floods during the third week of December 2015 and second week of January 2016.

In the interest of avoiding biased responses, the respondents were clearly selected to maintain heterogeneity. Members of multiple agencies such as the Tamil Nadu Water Board, Citizens Platform Chennai, Political Party, and representatives of the private companies involved in relief and local volunteers were interviewed. All responders were actively involved in relief activities, thereby providing first-hand information based on their experience and perception of the relief activities. We used the standard practices of disaster field research to rely on the dynamic process of interviews with the responders, documentation of conditions that prevail during and after disaster, identification and documentation of the lessons learned. Holguín-Veras et al. (2014) lists out the detailed overview of the structure of the standard practices followed during the disaster research. The interviews were conducted based on the methodology followed by Holguín-Veras et al. (2007) with a primary intention of providing a guide to the in-depth-interview rather than a formal questionnaire. The questions focused on assessing the level of involvement of the respondent with relief activities, familiarity with the humanitarian activities, obstacles faced during the relief operations, coordination issues experienced and observed during the relief activities and lessons learnt. The protocol was a set of open ended questions which could elicit a wide range of response from the responders. Each interview lasted between 60 and 90 min. The interviews were recorded with the consent of participants and transcribed upon requirement. In the interest of anonymity, the names and organizational affiliation of the respondents are not disclosed. In tandem with the field work, comprehensive media based data collection was carried out. Multiple media feeds such as newspaper, television, radio, blogs, social media feeds, etc. were collected and catalogued.

5.1 Data analysis

The proposed methodology has three main stages. The first step is the conversion of the responses of each respondent to fuzzy direct relationship matrix based on Table 1 as low, medium and high values. Subsequently, the average fuzzy direct relationship matrix is cal-

Table 3 Influence matrix for criterion using DEMATEL

Criterion	IS	MC	DA	OM
Information sharing (IS)	2.809	1.824	1.218	1.328
Material convergence (MC)	1.638	2.767	1.353	1.632
Diversity of actors (DA)	1.029	2.055	1.685	0.792
Organizational mandate (OM)	1.006	2.023	0.828	2.014

culated by taking the numerical average of the fuzzy direct relationship matrix for each respondent. Successively, the fuzzy total influence matrix is calculated using Eqs. (2) thorough (5) for all three levels. The fuzzy total influence matrix gives extent of relationship between each sub-factors. Since the total fuzzy matrix represents the fuzzy variations, we use CFCS defuzzification method as explained in the previous section using Eqs. (8)–(14) to obtain a single crisp value for each relationship as obtained in total fuzzy matrix. The defuzzified total influence matrix summarizes the influence of all sub-criteria affecting the coordination in HSC.

The next step was to derive the interdependence between each factor affecting the coordination in HSC. To identify the significant relationships, the total influence matrix ("Appendix"), for all the sub-factors is converted into the total influence matrix at factor level by taking the total sum of sub-factors representing the relationships. The total influence matrix for the criteria is given in Table 3, where each cell represents the strength of the relationships between the corresponding factors. The significant relationships between the factors are identified by setting the the threshold value of 1. Further, the influencing and influenced factors and sub factors are identified through the difference between row and column sums using Eqs. (6) and (7). The criteria with a positive $R-D$ score are the influencer variables whereas the criteria with negative $R-D$ score are the influenced variables. Table 4 summarizes the relational (R + D) and prominence (R − D) axis values for criterion and sub-criterion. The NRM for the criterion and sub-criterion is given in Fig. 1a is based on the significant relationships identified. Similarly, Fig. 1b–e shows the interdependence between the sub-factors within each factor.

The second stage of the proposed methodology focuses on linking the DEMATEL and ANP methodologies. ANP manages the inner dependency based on the total relationship matrix. The total relationship matrix is converted to unweighted inner dependency matrix for ANP by first converting all non-significant inter-dependence relationships at factor levels to zero and then using Eqs. (16)–(20). The limit matrix is calculated by raising the weighted matrix to a large integer (Eq. 21) value till the rows stabilize. The relative importance of each of criteria and sub criteria is summarized in Table 5. The average fuzzy direct relationship matrix, fuzzy total influence matrix, defuzzified influence matrix, unweighted super matrix, weighted super matrix and limit super matrix is given in appendix (Tables 6, 7, 8, 9, 10, 11).

6 Discussion and implications

The inter-dependence between the factors and sub-factors affecting the coordination and their respective weights are represented in the NRM (Fig. 1) and Table 5 respectively. From Fig. 1a and Table 5 we can observe that the information sharing (IS) is the main influencer variable with a relative importance score of 0.383. Inadequate and inefficient information sharing is affected by the large number of actors and their organization mandates. A lack of focus on

Table 4 The relational and prominence axis for cause and effect group

Criteria and Sub-criteria	R + D	R − D
Information sharing (IS)	13.66	0.70
Low priority for information sharing (IS1)	2.29	0.56
Lack of consistent data formats being shared among agencies (IS2)	2.10	0.99
Poor planning for coordination prior to relief operations (IS3)	2.08	0.65
Lack of uniform need assessment techniques (IS4)	4.32	− 1.28
Lack of knowledge about the requirement of beneficiaries (IS5)	2.88	− 0.22
Material convergence (MC)	16.06	− 1.28
Use of personnel for less essential task (MC1)	3.35	− 0.21
Competition between agencies for scarce resources (MC2)	3.29	− 0.56
Heterogeneous nature of aid material received (MC3)	2.77	0.11
Large quantities of non-priority items were received (MC4)	3.46	− 0.49
Scarcity and oversupply of aid materials (MC5)	3.18	− 0.13
Diversity of actors (DA)	10.65	0.48
Coordination based on the reputation of official (DA1)	2.16	0.39
Diverse nature of interacting agencies (DA2)	2.12	0.5
Large number of actors (DA3)	3.14	− 0.09
Lack of trust among interacting agencies (DA4)	3.23	− 0.33
Organizational mandates (OM)	11.64	0.11
Divergent set of interest for interacting agencies (OM1)	2.6	0.37
Varying donor expectation from relief operations (OM2)	3.46	− 0.39
Varying specialization of interacting agencies (OM3)	2.56	0.35
Lack of trust between International NGO and local NGO (OM4)	3.01	− 0.22

investing in improving coordination through information exchange during the pre-disaster preparedness phase results in low/improper information sharing between the humanitarian agencies in post-disaster relief phase. Further, lack of long term association in preparedness phase affects trust building between the agencies and further impedes information exchange in response phase. This is represented by a bidirectional relationship of IS with OM (0.197) and DA (160) is shown in Fig. 1a. Furthermore, material convergence (MC) is the influenced variable having direct impact of IS, DA and OM. Poor information sharing between the actors primarily due to lack of pre-disaster preparedness stage focus on improving information sharing between actors arising from diverse nature of actors and conflicting organizational mandates affects the post-disaster collaboration resulting in material convergence. Also, the convergence of both humanitarian actors and material at the disaster site in a chaotic post-disaster environment impedes coordination due to lack of long term agreements affecting the information sharing between the humanitarian agencies. These interactions are represented by the bi-directional arrows in Fig. 1a. IS has the most influence on the coordination in HSC followed by DA and OM, while MC is the most influenced factor in coordination.

Agencies were not predisposed to information sharing with other agencies. During Chennai floods, though a central coordination team was set up to coordinate the information sharing between various agencies, the sheer magnitude of the information generated from various sources made it difficult to segregate the information and compile them at an aggregate level. An estimated 200,000 emails, SMS, WhatsApp messages, Facebook and Twitter feeds were received at Chennai Relief Centre (CRC). This led to delays in gathering intelligence from

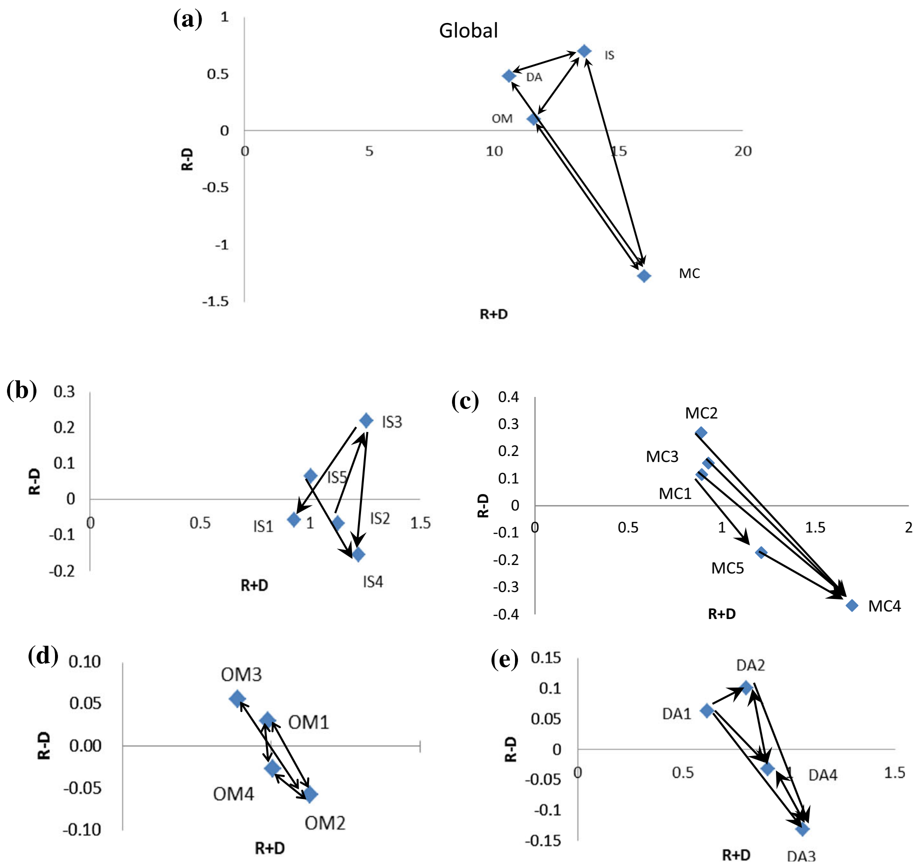

Fig. 1 Network relationship map. **a** Coordination issues in HSC. **b** Information sharing, **c** material convergence, **d** organizational mandates, **e** diversity of actors

information. One of the practical difficulty faced by the members of the CRC was locating the source of information. Subsequently, the coordination committee avoided aggregation of the information collected from various sources and merely focused on being a nodal agency to facilitate information exchange. This led to further confusion since it was expected that all information coming though the central coordination agency was verified and authenticated, which was not the case in every instance. This further added to the coordination woes during the floods relief operations.

Chennai floods were no different from a large scale disaster with a large number of actors involved in rescue and relief operations. Multiple actors were not aligned to coordinate with each other for the relief operations as there was no pre-disaster association between these agencies (IS3) leading low priority for information exchange (IS1) lack of any uniform assessment technique (IS4). The information sharing was not prioritized primarily due to two reasons: firstly, the actors were not experienced in responding to a major disaster leaving them new to such a chaotic situation. Secondly, many organizations had their specific agendas at the core of operations. This prevented the relief agencies form gauging the requirements of beneficiaries (IS5). For example, in the case of Cuddalore, a tier III town located about 100 km away from Chennai, religious and social groups prioritized relief distribution towards certain communities. The fishermen community in the Cuddalore district, primarily a Latin

Table 5 Relative importance of the criterion and sub-criterion

Criteria and sub-criteria	Relative importance (Avg.)
Information sharing (IS)	0.383
Low priority for information sharing (IS1)	0.139
Lack of consistent data formats being shared among agencies (IS2)	0.061
Poor planning for coordination prior to relief operations (IS3)	0.088
Lack of uniform need assessment techniques (IS4)	0.444
Lack of knowledge about the requirement of beneficiaries (IS5)	0.268
Material convergence (MC)	0.261
Use of personnel for less essential task (MC1)	0.202
Competition between agencies for scarce resources (MC2)	0.226
Heterogeneous nature of aid material received (MC3)	0.143
Large quantities of non-priority items were received (MC4)	0.246
Scarcity and oversupply of aid materials (MC5)	0.182
Diversity of actors (DA)	0.160
Coordination based on the reputation of official (DA1)	0.148
Diverse nature of interacting agencies (DA2)	0.148
Large number of actors (DA3)	0.305
Lack of trust among interacting agencies (DA4)	0.399
Organizational mandates (OM)	0.197
Divergent set of interest for interacting agencies (OM1)	0.186
Varying donor expectation from relief operations (OM2)	0.388
Varying specialization of interacting agencies (OM3)	0.134
Lack of trust between International NGO and local NGO (OM4)	0.292

Catholic community experienced marginalisation during the aid distribution organised by other religious groups. The interactions between the sub-factors under information sharing are shown in Fig. 1b.

The lack of pre-defined operational procedures hindered the effective relief operations and the local government, had to depend upon the other organizations. This dependence was perceived as a lack of efficiency on the part of local government. Mistrust between the agencies led to poor information sharing and poor coordination between government and NGO's (OM4). The organization clusters formed to improve coordination were expected to have better access to resources such as aid material, donors, logistics supports, trained volunteers, etc. Yet, smaller organizations were not a part of these clusters since they did not have any specific complimenting capabilities (OM3). Some of the smaller volunteer groups, which were formed primarily for the Chennai floods relief activities, were overwhelmed by the chaotic environment and focussed on delivering the aid at the earliest and leaving (OM2). There were multiple instances when the volunteers delivered to the first person in sight and often at the sites that were easily accessible. These led to a few people receiving relief multiple times and while others being completely ignored even within the same locality. These interactions are shown in Fig. 1d.

The magnitude and destruction associated with the Chennai floods received significant coverage in news and social media and a large number of voluntary relief workers arrived at the disaster scene with aid material with little or no prior understanding of the situation (DA3).

Some of the local organizations within Chennai and Tamil Nadu circuit formed coordination clusters primarily to share resources such as vehicles and other modes of transport, common storage areas and identification of location for aid distribution centres (DA1). However, the coordination clusters formed were selective in allowing NGOs to be part of the cluster and depended on the political and religious affiliations of the NGOs (DA2) and hence certain smaller NGOs representing marginalized groups were excluded these clusters. In one of the incidents reported from Chennai, where Irular community (scheduled caste) were ignored for any sort of aid assistance for almost a week after the Chennai floods. Furthermore, the coordination was also affected by the opportunistic behaviour of many organizations (DA4). For instance, one of the interviewee representing a NGO recalled that multiple new and spurious NGO's were formed to siphon cash and hoard donations anticipating an arbitrage opportunity in future. Thus, NGOs viewed with others with suspicion and much effort was spent on analysing the authenticity of claims and impeding coordination. These interactions are shown in Fig. 1e.

Material convergence (MC) was a direct result of lack of poor coordination between agencies and was worsened by large number of actors, and poor information sharing between these actors. Many experts during the interviews recounted that managing the large amounts of supplies arriving at the site and the waste generation due to the relief material was a huge issue (MC4). An estimated 1 million packets of biscuits, 5000 litres of milk, 10,000 tonnes of instant noodles were sent to Chennai. Another challenge faced during the relief efforts was the recirculation of the information. During Chennai floods, the social media turned out to be quite helpful for gathering and spreading information which helped in saving many lives. However, due to recirculation of the information in the social media, the need assessment was affected (MC5). This resulted in the influx of large amount of aid material which affected the storage, since almost all storage units (hall, godowns, etc.) was flooded with aid materials (MC3). A classic example of the information duplication was found in case of the water bottles required. A social media tweet by an in charge of one of the public kitchen requesting for the 500 water bottles was re-tweeted multiple time leading to a receipts of more than 10,000 water bottles. Soon this material convergence became the concern in terms of storage and disposal of the used plastic water bottles (MC1). Furthermore, with large number of organisations involved in the relief activities, there were no official records available as to whom how, or where these aid material distributed. This led to large number of smaller organizations competing for scarce resources, which resulted in poor coordination between the organizations (MC2). These interactions are summarized in Fig. 1c.

6.1 Implications

The study of Chennai flood rescue and relief activities shed light on the coordination challenges faced during any large scale disaster. It can be noted that the coordination challenges discussed by previous studies such Balcik et al. (2010), Stephenson (2005) and Van Wassenhove (2006) were relevant during the Chennai flood relief activities. While Balcik et al. (2010) and Stephenson (2005) explored the coordination challenges in HSC based on a general setting; Van Wassenhove (2006) studied coordination during Gujarat earthquake and Mozambique floods. This indicates that even though the disasters are assumed to be unique (Day et al. 2012), the coordination challenges in HSC follows a pattern and repeatability. This section provides few implications for improving the coordination in HSC.

Firstly, the interacting agencies need to prioritize the identification of the actual need of the beneficiaries by involving local level leaders or in consultation with the affected people rather than trying to force fit the existing solutions. The concept of force fitting the relief solution has been criticized in the literature (Van Wassenhove 2006; Kovács and Spens 2011; Jahre and Jensen 2010). During the relief activities of hurricane Katrina, FEMA used the municipal database to profile the recipients to get a better idea of the nature of the critical supplies to be channelized form the central warehouses (Holguín-Veras et al. 2007).

Second, the humanitarian agencies should work towards formation of a common consortium of actors focusing on creating a standardized need assessment template for easy sharing and comprehension of information. The inter-agency standing committees (ISAC) are examples which can be replicated at local levels as well. ISAC and Office for Coordination of Humanitarian Affairs (OCHA) have developed a need assessment template to be followed by the member organization with the primary motive of fostering inter-operability of information collected.

Third, the common knowledge database in association with localized consortiums to share supplies should be created. This could help in transfer of supplies from points of oversupply to points of scarcity. During Chennai floods, the social media played a pivotal role in the dissemination of information which helped save lives of many. However, due to recirculation of the information, the tracking the relevant of information had become a major challenge and affected the coordination of the relief activities. The use of data mining processes and creating knowledge database could help in streamlining the information processing for effective coordination. Hristidis et al. (2010) proposed a Business Continuity Information Network (BCIN) with the collaboration with the Miami-Dade County emergency management office aiding in data mining with spatial pattern recognition for targeted relief operations.

Fourth, the relief agencies should focus on the long term rehabilitation during the initial stages of the relief activities itself. Usually, the rehabilitation activities are decoupled from the relief activities and are carried out by separate set of actors. The smooth transition of the relief to rehabilitation phase of the disaster management can be achieved by streamlining the interest of the various agencies by sharing of the common resources and focusing on the organizational expertise. Depending upon the organization expertise, the resources and timeline of the relief operations can be targeted upon.

Finally, establishing a strong central command for coordination with various stakeholders during the preparedness stage rather than waiting to form a coordination unit post disaster can go a long way in effective coordination between the various organizations in HSC. To improve the coordination between the central and local governments in the aftermath of the hurricane Katrina, FEMA use national emergency management system which links the local governments with the federal agencies helping in join procurement, tracking and delivery of the supplies for disaster relief. This mechanism operates with the close association with local government empowering them to respond efficiently.

7 Conclusion

The importance of coordination between the actors in HSC is considered as one of the major factors for the effectiveness of the humanitarian operations. Though the need for coordination is well appreciated, the studies exploring the factors affecting coordination and the nature of inter dependence of these factors has received much less interest in the academic literature. This study focused on exploring this inter-dependence between the factors affecting coordination. Based on the literature review and interviews conducted with the experts who had actively took part in the relief activities post Chennai floods, four major criteria namely material convergence, diversity of actors, poor information sharing between the agencies, and varying organizational mandates were identified, which are impediments to effective coordination in HSC. To identify the inter-dependence between the criterion, a hybrid fuzzy DEMATEL-ANP methodology is being used. The fuzzy DEMATEL part provides the NRM between the criterion and sub criterion, whereas the ANP is used to obtain the weights of each criteria and sub-criteria.

The results indicate that information sharing between the agencies and the diversity of the actors are the most important criterion which acts as an impediment to the coordination in HSC. The NRM shows material convergence is the influenced variable, whereas the information sharing is the most important influencer variable and diverse nature of HA and their organizational mandates both influence the information sharing between the agencies. Since most of the HAs operate on the donations, the focus is often on the post-disaster relief operation rather than pre-disaster capability building. One of the direct impacts of this is in terms of poor coordination between the agencies in the post-disaster relief operations. With each disaster situation presenting itself with unique set of challenges, most of relief time coordination is based on informal relationships are adhoc in nature. This kind of association compounds the coordination challenge owing to lack of trust between actors, varying organizational mandates, diverse nature of actors, competition between the actors, improper needs assessments and poor information exchange between actors. Poor coordination often manifest itself in terms of inequitable aid distribution, wastage of aid material, scarcity of priority items and oversupply of non-priority items leading to increased suffering of the affected people. Often poor coordination leads to a secondary disaster (Van Wassenhove 2006). We have used Chennai floods as a case study to explore these inter-relationships through the experiences and learning's from the experiences of the respondents directly involved with the relief activities during the Chennai flood relief.

In this study we make three major contributions to the HSC literature. Firstly, we explore the relationships between the multiple factors affecting coordination. Though extant literature talks about the coordination in HSC and the factors affecting coordination, it is silent on the nature of interaction between these factors. Secondly, we identify the major challenges that influence the effectiveness of coordination in HSC and how these factors operate during the relief operations. Finally, the empirical investigation based on a large scale disaster like Chennai floods help to better understand the practical implications of the coordination in HSC and how these factors affect the effectiveness of relief activities. In this study, we have primarily focused on the observations, anecdotal evidences, and findings based on Chennai floods. The generalizability of the NRM model presented in this study would benefit from being tested in other disaster scenarios. Further, a formal statistical evaluation of the inter-relationships could also help towards the generalizability of the findings.

Acknowledgements The authors would like to thank the members of Tamil Nadu Water Board, Communist Party of India (Marxist), Ms. Saritha Sugunan (Pepper Corn), Prof. Gladston Xavier, and all others who shared their valuable experience and insights on their experience during the Chennai Floods.

Appendix

See Tables 6, 7, 8, 9, 10 and 11.

Table 6 Average fuzzy direct-relationship matrix

	IS1	IS2	IS3	IS4	IS5	MC1	MC2	MC3	MC4	MC5	DA1	DA2	DA3	DA4	OM1	OM2	OM3	OM4
IS1	0, 0, 0	0.36, 0.56, 0.75	0.28, 0.45, 0.65	0.45, 0.65, 0.81	0.14, 0.31, 0.51	0.28, 0.48, 0.68	0.14, 0.31, 0.51	0.44, 0.64, 0.83	0.48, 0.68, 0.87	0.57, 0.77, 0.93	0.14, 0.31, 0.51	0.14, 0.31, 0.51	0.51, 0.71, 0.87	0.1, 0.27, 0.47	0.19, 0.34, 0.52	0.46, 0.66, 0.83	0.13, 0.33, 0.53	0.07, 0.25, 0.45
IS2	0.4, 0.6, 0.8	0, 0, 0	0.23, 0.43, 0.63	0.23, 0.43, 0.63	0.23, 0.43, 0.63	0.28, 0.48, 0.68	0.13, 0.33, 0.53	0.47, 0.67, 0.85	0.14, 0.31, 0.51	0.14, 0.31, 0.51	0.14, 0.31, 0.51	0.51, 0.71, 0.87	0.51, 0.71, 0.87	0.53, 0.73, 0.91	0.53, 0.73, 0.91	0.51, 0.71, 0.87	0.57, 0.77, 0.93	0.57, 0.77, 0.93
IS3	0.13, 0.32, 0.52	0.1, 0.3, 0.5	0, 0, 0	0.21, 0.39, 0.59	0.21, 0.39, 0.59	0.17, 0.36, 0.56	0.21, 0.41, 0.61	0.17, 0.37, 0.57	0.13, 0.31, 0.51	0.47, 0.67, 0.83	0.21, 0.39, 0.59	0.21, 0.39, 0.59	0.42, 0.62, 0.81	0.53, 0.73, 0.89	0.41, 0.61, 0.81	0.46, 0.66, 0.83	0.24, 0.44, 0.64	0.18, 0.36, 0.56
IS4	0.35, 0.55, 0.75	0.19, 0.38, 0.58	0.05, 0.2, 0.4	0, 0, 0	0.47, 0.67, 0.83	0.44, 0.64, 0.8	0.46, 0.66, 0.86	0.53, 0.73, 0.89	0.38, 0.58, 0.78	0.53, 0.73, 0.89	0.27, 0.47, 0.67	0.31, 0.51, 0.71	0.47, 0.67, 0.85	0.37, 0.57, 0.77	0.46, 0.66, 0.83	0.53, 0.73, 0.91	0.54, 0.74, 0.92	0.46, 0.66, 0.84
IS5	0.02, 0.14, 0.34	0.1, 0.3, 0.5	0.13, 0.32, 0.52	0.5, 0.7, 0.9	0, 0, 0	0.23, 0.43, 0.63	0.26, 0.46, 0.66	0.37, 0.57, 0.77	0.34, 0.54, 0.74	0.21, 0.39, 0.59	0.21, 0.39, 0.59	0.17, 0.34, 0.54	0.25, 0.45, 0.65	0.17, 0.37, 0.57	0.5, 0.7, 0.88	0.46, 0.66, 0.84	0.4, 0.6, 0.8	0.37, 0.57, 0.77
MC1	0.2, 0.4, 0.6	0.4, 0.6, 0.8	0.38, 0.58, 0.78	0.43, 0.63, 0.83	0.19, 0.38, 0.58	0, 0, 0	0.57, 0.77, 0.93	0.63, 0.83, 0.97	0.46, 0.66, 0.86	0.46, 0.66, 0.86	0.21, 0.39, 0.59	0.21, 0.39, 0.59	0.48, 0.68, 0.87	0.1, 0.28, 0.48	0.28, 0.48, 0.68	0.57, 0.77, 0.93	0.1, 0.27, 0.47	0.51, 0.71, 0.87
MC2	0.02, 0.14, 0.34	0.14, 0.34, 0.54	0.14, 0.34, 0.54	0.52, 0.72, 0.9	0.34, 0.54, 0.74	0.67, 0.87, 0.99	0, 0, 0	0.09, 0.24, 0.44	0.61, 0.81, 0.96	0.55, 0.75, 0.93	0.12, 0.27, 0.47	0.18, 0.35, 0.55	0.53, 0.73, 0.89	0.42, 0.62, 0.79	0.31, 0.51, 0.71	0.36, 0.56, 0.74	0.2, 0.38, 0.58	0.07, 0.22, 0.42
MC3	0.35, 0.55, 0.75	0.38, 0.58, 0.78	0.38, 0.58, 0.78	0.35, 0.55, 0.75	0.35, 0.55, 0.75	0.6, 0.8, 0.92	0.05, 0.2, 0.4	0, 0, 0	0.47, 0.67, 0.83	0.47, 0.67, 0.83	0.42, 0.62, 0.81	0.26, 0.46, 0.66	0.17, 0.35, 0.55	0.46, 0.66, 0.86	0.21, 0.41, 0.61	0.21, 0.41, 0.61	0.17, 0.35, 0.55	0.33, 0.53, 0.73
MC4	0.27, 0.47, 0.67	0.14, 0.34, 0.54	0.02, 0.14, 0.34	0.67, 0.87, 0.99	0.67, 0.87, 0.99	0.32, 0.52, 0.72	0.54, 0.74, 0.92	0.3, 0.5, 0.7	0, 0, 0	0.59, 0.79, 0.92	0.59, 0.79, 0.92	0.39, 0.59, 0.79	0.39, 0.59, 0.79	0.42, 0.62, 0.81	0.42, 0.62, 0.82	0.33, 0.53, 0.73	0.19, 0.37, 0.57	0.38, 0.58, 0.77
MC5	0.29, 0.49, 0.69	0.19, 0.38, 0.58	0.51, 0.71, 0.88	0.53, 0.73, 0.9	0.05, 0.2, 0.4	0.55, 0.75, 0.9	0.65, 0.85, 0.97	0.51, 0.71, 0.88	0.31, 0.51, 0.71	0, 0, 0	0.17, 0.34, 0.54	0.34, 0.54, 0.74	0.34, 0.54, 0.74	0.15, 0.33, 0.53	0.26, 0.46, 0.66	0.32, 0.52, 0.72	0.39, 0.59, 0.79	0.39, 0.59, 0.79

Table 6 continued

	IS1	IS2	IS3	IS4	IS5	MC1	MC2	MC3	MC4	MC5	DA1	DA2	DA3	DA4	OM1	OM2	OM3	OM4
DA1	0.02, 0.14, 0.34	0.02, 0.14, 0.34	0.02, 0.14, 0.34	0.27, 0.47, 0.67	0.14, 0.34, 0.54	0.03, 0.17, 0.37	0.03, 0.17, 0.37	0.37, 0.57, 0.77	0.54, 0.74, 0.91	0.13, 0.33, 0.53	0, 0, 0	0.54, 0.74, 0.9	0.54, 0.74, 0.9	0.53, 0.73, 0.89	0.23, 0.43, 0.63	0.2, 0.4, 0.6	0.07, 0.22, 0.42	0.25, 0.45, 0.65
DA2	0.05, 0.2, 0.4	0.33, 0.53, 0.73	0.19, 0.38, 0.58	0.55, 0.75, 0.9	0.2, 0.4, 0.6	0.19, 0.38, 0.58	0.35, 0.55, 0.75	0.19, 0.38, 0.58	0.18, 0.35, 0.55	0.35, 0.55, 0.75	0.38, 0.58, 0.78	0, 0, 0	0.07, 0.24, 0.44	0.46, 0.66, 0.86	0.28, 0.48, 0.68	0.33, 0.53, 0.73	0.47, 0.67, 0.85	0.17, 0.37, 0.57
DA3	0.34, 0.54, 0.74	0.54, 0.74, 0.92	0.52, 0.72, 0.9	0.27, 0.47, 0.67	0.27, 0.47, 0.67	0.32, 0.52, 0.72	0.52, 0.72, 0.9	0.14, 0.34, 0.54	0.14, 0.34, 0.54	0.14, 0.34, 0.54	0.52, 0.72, 0.9	0.14, 0.34, 0.54	0, 0, 0	0.61, 0.81, 0.96	0.28, 0.48, 0.68	0.53, 0.73, 0.89	0.46, 0.66, 0.86	0.24, 0.44, 0.64
DA4	0.05, 0.2, 0.4	0.31, 0.51, 0.71	0.53, 0.73, 0.9	0.58, 0.78, 0.93	0.18, 0.35, 0.55	0.13, 0.31, 0.51	0.42, 0.62, 0.8	0.43, 0.63, 0.83	0.51, 0.71, 0.88	0.1, 0.25, 0.45	0.51, 0.71, 0.88	0.31, 0.51, 0.71	0.55, 0.75, 0.9	0, 0, 0	0.28, 0.48, 0.68	0.54, 0.74, 0.9	0.54, 0.74, 0.9	0.53, 0.73, 0.89
OM1	0.67, 0.87, 0.99	0.52, 0.72, 0.9	0.52, 0.72, 0.9	0.27, 0.47, 0.67	0.54, 0.74, 0.92	0.13, 0.32, 0.52	0.67, 0.87, 0.99	0.27, 0.47, 0.67	0.67, 0.87, 0.99	0.1, 0.3, 0.5	0.67, 0.87, 0.99	0.34, 0.54, 0.74	0.34, 0.54, 0.74	0.5, 0.7, 0.9	0, 0, 0	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.5, 0.7, 0.9
OM2	0.51, 0.71, 0.88	0.38, 0.58, 0.78	0.53, 0.73, 0.9	0.65, 0.85, 0.97	0.51, 0.71, 0.88	0.53, 0.73, 0.87	0.38, 0.58, 0.78	0.55, 0.75, 0.9	0.51, 0.71, 0.88	0.65, 0.85, 0.97	0.19, 0.38, 0.58	0.51, 0.71, 0.88	0.31, 0.51, 0.71	0.55, 0.75, 0.9	0.35, 0.55, 0.75	0, 0, 0	0.3, 0.5, 0.7	0.5, 0.7, 0.9
OM3	0.03, 0.17, 0.37	0.54, 0.74, 0.92	0.35, 0.55, 0.74	0.57, 0.77, 0.93	0.54, 0.74, 0.92	0.13, 0.32, 0.52	0.14, 0.34, 0.54	0.1, 0.3, 0.5	0.14, 0.34, 0.54	0.14, 0.34, 0.54	0.14, 0.34, 0.54	0.52, 0.72, 0.9	0.47, 0.67, 0.87	0.3, 0.5, 0.7	0.12, 0.29, 0.49	0.47, 0.67, 0.87	0, 0, 0	0.38, 0.58, 0.77
OM4	0.11, 0.27, 0.47	0.42, 0.62, 0.8	0.11, 0.27, 0.47	0.45, 0.65, 0.83	0.45, 0.65, 0.83	0.53, 0.73, 0.87	0.1, 0.25, 0.45	0.22, 0.4, 0.6	0.42, 0.62, 0.8	0.38, 0.58, 0.78	0.18, 0.35, 0.55	0.23, 0.42, 0.62	0.22, 0.4, 0.6	0.55, 0.75, 0.9	0.48, 0.68, 0.83	0.23, 0.42, 0.62	0.4, 0.6, 0.77	0, 0, 0

Table 7 Fuzzy total influence matrix

	IS1	IS2	IS3	IS4	IS5	MC1	MC2	MC3	MC4	MC5	DA1	DA2	DA3	DA4	OM1	OM2	OM3	OM4
IS1	0.01, −0.12, −0.5	0.01, 0.01, 0.01	0.06, 0.09, 0.09	0, −0.08, −0.36	−0.16, −0.27, −0.41	0.1, 0.16, 0.06	−0.01, −0.03, −0.2	0.1, 0.15, 0.07	0.03, −0.01, −0.17	0.22, 0.3, 0.19	−0.12, −0.2, −0.26	−0.13, −0.2, −0.25	0.07, 0.06, −0.09	−0.17, −0.29, −0.47	−0.08, −0.16, −0.29	0.03, 0, −0.19	−0.15, −0.24, −0.34	−0.14, −0.22, −0.37
IS2	0.01, 0.04, 0.17	−0.06, −0.23, −0.65	0.02, 0.04, 0.06	−0.09, −0.18, −0.47	−0.02, −0.05, −0.2	−0.14, −0.25, −0.39	−0.22, −0.33, −0.5	−0.01, −0.06, −0.16	−0.17, −0.28, −0.47	−0.21, −0.33, −0.46	−0.07, −0.11, −0.18	0.1, 0.13, 0.06	0, −0.04, −0.18	0.12, 0.12, −0.05	0.04, 0.04, −0.04	0.06, 0.04, −0.15	0.17, 0.22, 0.09	0.12, 0.11, −0.07
IS3	−0.06, −0.05, 0.03	−0.07, −0.08, −0.08	−0.06, −0.23, −0.64	−0.05, −0.13, −0.42	−0.05, −0.11, −0.25	−0.08, −0.13, −0.29	0, −0.02, −0.19	−0.08, −0.12, −0.23	−0.07, −0.14, −0.33	0.02, 0, −0.15	−0.01, −0.03, −0.08	−0.02, −0.05, −0.09	0.06, 0.05, −0.08	0.12, 0.11, −0.06	0.03, 0.01, −0.06	0.07, 0.04, −0.13	0.01, −0.01, −0.1	−0.04, −0.11, −0.27
IS4	0.01, 0.05, 0.13	−0.06, −0.09, −0.11	−0.11, −0.16, −0.22	−0.19, −0.48, −1.18	0.02, −0.02, −0.17	0.08, 0.09, −0.08	0.04, 0.02, −0.13	0.05, 0.04, −0.08	−0.01, −0.04, −0.2	0.08, 0.08, −0.07	−0.1, −0.14, −0.17	−0.08, −0.12, −0.14	−0.01, −0.06, −0.21	−0.11, −0.19, −0.36	−0.02, −0.05, −0.16	0.01, −0.05, −0.24	0, −0.05, −0.15	0, −0.04, −0.21
IS5	−0.08, −0.12, −0.11	−0.09, −0.11, −0.12	−0.12, −0.15, −0.18	0.08, 0.03, −0.24	−0.07, −0.28, −0.82	−0.01, −0.05, −0.19	−0.01, −0.04, −0.2	0.01, −0.01, −0.12	0.05, 0.03, −0.15	−0.04, −0.09, −0.25	−0.02, −0.03, −0.1	−0.05, −0.08, −0.13	−0.07, −0.12, −0.27	−0.07, −0.12, −0.29	0.08, 0.08, −0.01	0.02, −0.02, −0.21	0.02, 0, −0.07	0.05, 0.03, −0.1
MC1	0.05, 0.11, 0.17	−0.02, −0.03, −0.06	0.02, 0.05, 0.05	−0.03, −0.12, −0.4	−0.13, −0.22, −0.37	−0.03, −0.19, −0.75	0.11, 0.13, −0.02	0.12, 0.14, −0.01	0.04, 0.02, −0.14	0.15, 0.21, 0.1	−0.13, −0.2, −0.24	−0.15, −0.24, −0.29	0.01, −0.02, −0.15	−0.17, −0.29, −0.48	−0.05, −0.09, −0.18	0.01, −0.04, −0.25	−0.2, −0.33, −0.47	0, −0.07, −0.24
MC2	−0.07, −0.09, −0.09	−0.13, −0.17, −0.18	−0.08, −0.07, −0.05	0.06, 0, −0.26	−0.04, −0.07, −0.15	0.23, 0.28, 0.06	0.01, −0.16, −0.73	−0.08, −0.12, −0.27	0.13, 0.11, −0.1	0.16, 0.19, 0.04	−0.11, −0.18, −0.24	−0.15, −0.23, −0.25	0.08, 0.06, −0.09	−0.1, −0.17, −0.32	−0.04, −0.06, −0.12	−0.01, −0.04, −0.21	−0.14, −0.22, −0.27	−0.13, −0.22, −0.37
MC3	0.04, 0.08, 0.15	−0.02, −0.03, −0.01	0, 0, 0.03	−0.02, −0.09, −0.36	−0.06, −0.1, −0.21	0.12, 0.09, −0.16	−0.1, −0.19, −0.43	−0.1, −0.31, −0.86	0.06, 0.03, −0.18	0.08, 0.07, −0.12	0.04, 0.05, 0.02	−0.04, −0.06, −0.06	−0.06, −0.12, −0.28	−0.02, −0.06, −0.17	−0.06, −0.08, −0.16	−0.08, −0.14, −0.32	−0.12, −0.17, −0.23	0, −0.03, −0.16
MC4	−0.08, −0.06, 0.06	−0.19, −0.23, −0.2	−0.24, −0.34, −0.35	0.14, 0.09, −0.27	0.12, 0.1, −0.11	0.02, 0.03, −0.09	0.13, 0.14, −0.02	−0.02, −0.03, −0.12	−0.09, −0.31, −0.91	0.1, 0.1, −0.07	0.1, 0.1, 0.02	−0.04, −0.07, −0.09	−0.03, −0.07, −0.19	−0.07, −0.15, −0.31	0, −0.02, −0.11	−0.08, −0.16, −0.33	−0.12, −0.2, −0.31	−0.03, −0.08, −0.24
MC5	0.04, 0.1, 0.16	−0.07, −0.09, −0.09	0.1, 0.15, 0.13	0.03, −0.05, −0.34	−0.17, −0.29, −0.44	0.21, 0.27, 0.06	0.19, 0.2, −0.04	0.05, 0.06, −0.06	−0.02, −0.07, −0.26	−0.03, −0.2, −0.78	−0.16, −0.24, −0.28	−0.1, −0.16, −0.14	0.01, −0.03, −0.17	−0.17, −0.28, −0.43	−0.07, −0.13, −0.21	−0.03, −0.08, −0.26	−0.09, −0.16, −0.21	−0.07, −0.13, −0.25

Table 7 continued

	IS1	IS2	IS3	IS4	IS5	MC1	MC2	MC3	MC4	MC5	DA1	DA2	DA3	DA4	OM1	OM2	OM3	OM4
DA1	−0.18, −0.26, −0.2	−0.1, −0.18, −0.23	−0.17, −0.27, −0.31	0.04, 0.03, −0.2	0.02, 0.06, −0.06	−0.19, −0.33, −0.47	−0.09, −0.18, −0.35	0, −0.04, −0.11	0.12, 0.14, 0	−0.16, −0.25, −0.36	0.04, −0.07, −0.52	0.19, 0.25, 0.2	0.07, 0.04, −0.1	0.21, 0.25, 0.09	0, 0, −0.07	−0.06, −0.12, −0.3	0, 0, −0.11	0.02, 0.02, −0.11
DA2	−0.15, −0.2, −0.15	0, 0.01, 0.02	−0.07, −0.09, −0.09	0.11, 0.07, −0.24	0, −0.01, −0.15	−0.09, −0.16, −0.31	0.01, −0.04, −0.21	−0.06, −0.12, −0.23	−0.06, −0.13, −0.32	−0.05, −0.11, −0.24	0.03, 0.03, −0.01	−0.09, −0.28, −0.72	−0.09, −0.15, −0.32	0.08, 0.07, −0.07	−0.01, −0.02, −0.1	0.01, −0.03, −0.21	0.13, 0.16, 0.08	−0.01, −0.03, −0.18
DA3	−0.05, −0.04, 0.08	0.08, 0.1, 0.11	0.11, 0.15, 0.14	−0.07, −0.16, −0.44	−0.03, −0.08, −0.22	−0.12, −0.2, −0.33	−0.01, −0.07, −0.26	−0.12, −0.19, −0.3	−0.12, −0.2, −0.39	−0.18, −0.26, −0.38	0.06, 0.06, −0.01	−0.04, −0.04, −0.08	−0.13, −0.36, −0.93	0.17, 0.18, −0.05	−0.03, −0.06, −0.14	0.09, 0.06, −0.13	0.08, 0.1, 0.01	−0.04, −0.08, −0.24
DA4	−0.2, −0.26, −0.19	−0.04, −0.03, 0	0, −0.01, 0	0.05, 0, −0.3	0.01, 0, −0.14	−0.18, −0.32, −0.5	−0.05, −0.13, −0.33	−0.07, −0.13, −0.23	0, −0.05, −0.23	−0.2, −0.34, −0.52	0.11, 0.15, 0.11	0.03, 0.07, 0.07	0.04, 0.01, −0.15	−0.08, −0.27, −0.82	−0.02, −0.03, −0.1	0.03, −0.01, −0.2	0.12, 0.16, 0.08	0.07, 0.07, −0.09
OM1	0.05, 0.07, 0.11	−0.05, −0.06, 0	−0.07, −0.09, −0.02	−0.05, −0.12, −0.42	0.08, 0.07, −0.07	−0.16, −0.27, −0.46	0.06, 0, −0.28	−0.09, −0.15, −0.27	0.14, 0.11, −0.19	−0.14, −0.21, −0.4	0.15, 0.18, 0.05	−0.02, −0.02, −0.02	−0.02, −0.05, −0.21	0.05, 0.03, −0.09	−0.18, −0.43, −0.93	−0.02, −0.07, −0.21	−0.08, −0.1, −0.11	−0.02, −0.06, −0.16
OM2	0.08, 0.13, 0.17	−0.06, −0.07, −0.05	0.04, 0.07, 0.05	0.04, −0.04, −0.37	−0.06, −0.12, −0.22	0.12, 0.13, −0.1	0.01, −0.02, −0.2	0.07, 0.07, −0.1	0.01, −0.05, −0.24	0.17, 0.19, −0.04	−0.17, −0.23, −0.25	−0.06, −0.11, −0.12	−0.09, −0.14, −0.27	−0.09, −0.18, −0.33	−0.07, −0.11, −0.16	−0.24, −0.52, −1.12	−0.12, −0.18, −0.23	−0.03, −0.08, −0.2
OM3	−0.15, −0.21, −0.17	0.14, 0.19, 0.19	0.02, 0.03, 0.04	0.07, 0.02, −0.27	0.14, 0.16, 0.02	−0.15, −0.27, −0.44	−0.14, −0.24, −0.43	−0.13, −0.2, −0.32	−0.19, −0.29, −0.48	−0.19, −0.3, −0.45	−0.1, −0.12, −0.17	0.12, 0.17, 0.15	0, −0.04, −0.16	0.06, 0.07, −0.07	−0.02, −0.04, −0.14	0.09, 0.07, −0.08	0.01, −0.14, −0.64	0.09, 0.09, −0.05
OM4	−0.09, −0.1, −0.02	0.05, 0.07, 0.07	−0.12, −0.16, −0.17	0.02, −0.03, −0.3	0.08, 0.09, −0.05	0.02, −0.03, −0.19	−0.09, −0.18, −0.38	−0.04, −0.08, −0.18	0.01, −0.03, −0.22	−0.07, −0.13, −0.23	−0.05, −0.07, −0.14	−0.03, −0.03, −0.05	−0.07, −0.14, −0.29	0.05, 0.02, −0.18	0.07, 0.07, −0.04	−0.05, −0.1, −0.28	0.05, 0.06, −0.01	−0.1, −0.32, −0.88

Table 8 Defuzzified fuzzy influence matrix for DEMATEL

	IS1	IS2	IS3	IS4	IS5	MC1	MC2	MC3	MC4	MC5	DA1	DA2	DA3	DA4	OM1	OM2	OM3	OM4
IS1	0.21	0.00	0.02	0.14	0.13	0.01	0.07	0.00	0.08	0.02	0.08	0.07	0.06	0.15	0.10	0.08	0.09	0.11
IS2	0.07	0.26	0.02	0.16	0.07	0.12	0.14	0.06	0.14	0.13	0.05	0.00	0.07	0.05	0.03	0.08	0.01	0.06
IS3	0.04	0.01	0.25	0.16	0.09	0.09	0.07	0.07	0.11	0.07	0.03	0.03	0.05	0.06	0.04	0.07	0.04	0.10
IS4	0.05	0.03	0.05	0.46	0.08	0.05	0.06	0.04	0.07	0.05	0.04	0.03	0.08	0.12	0.06	0.10	0.07	0.08
IS5	0.02	0.02	0.03	0.12	0.33	0.07	0.07	0.05	0.07	0.09	0.03	0.04	0.09	0.09	0.03	0.10	0.04	0.05
MC1	0.06	0.02	0.02	0.16	0.12	0.30	0.04	0.03	0.07	0.00	0.06	0.08	0.07	0.15	0.06	0.10	0.14	0.10
MC2	0.02	0.03	0.01	0.12	0.05	0.04	0.30	0.08	0.08	0.03	0.07	0.06	0.06	0.10	0.04	0.08	0.08	0.12
MC3	0.05	0.00	0.01	0.14	0.07	0.10	0.14	0.34	0.09	0.07	0.00	0.01	0.09	0.06	0.04	0.10	0.06	0.06
MC4	0.06	0.02	0.08	0.15	0.08	0.03	0.05	0.04	0.36	0.05	0.02	0.03	0.07	0.11	0.05	0.11	0.10	0.09
MC5	0.06	0.01	0.02	0.15	0.14	0.03	0.07	0.03	0.09	0.31	0.07	0.03	0.07	0.13	0.06	0.09	0.07	0.08
DA1	0.04	0.07	0.09	0.08	0.01	0.15	0.12	0.05	0.03	0.10	0.22	0.03	0.06	0.03	0.02	0.10	0.04	0.04
DA2	0.02	0.01	0.01	0.12	0.05	0.10	0.09	0.08	0.11	0.09	0.01	0.28	0.10	0.05	0.04	0.08	0.01	0.06
DA3	0.05	0.02	0.02	0.15	0.08	0.11	0.11	0.08	0.12	0.10	0.02	0.01	0.36	0.07	0.05	0.08	0.02	0.08
DA4	0.02	0.01	0.00	0.13	0.05	0.16	0.12	0.08	0.09	0.17	0.02	0.03	0.07	0.32	0.03	0.09	0.00	0.05
OM1	0.02	0.01	0.02	0.15	0.05	0.14	0.13	0.08	0.12	0.12	0.03	0.00	0.07	0.05	0.35	0.08	0.02	0.06
OM2	0.04	0.00	0.01	0.16	0.08	0.06	0.08	0.06	0.10	0.06	0.05	0.04	0.08	0.11	0.04	0.42	0.06	0.07
OM3	0.03	0.03	0.01	0.13	0.04	0.14	0.14	0.09	0.14	0.13	0.03	0.02	0.07	0.04	0.05	0.06	0.26	0.04
OM4	0.02	0.01	0.03	0.12	0.04	0.09	0.13	0.06	0.09	0.07	0.04	0.01	0.10	0.09	0.04	0.10	0.02	0.34

Table 9 Unweighted super matrix

	IS1	IS2	IS3	IS4	IS5	MC1	MC2	MC3	MC4	MC5	DA1	DA2	DA3	DA4	OM1	OM2	OM3	OM4
IS1	0	0	0	0	0	0.165	0.065	0.174	0.156	0.153	0	0	0	0	0	0	0	0
IS2	0	0	0	0	0	0.053	0.136	0.009	0.049	0.034	0	0	0	0	0	0	0	0
IS3	0	0	0	0	0	0.047	0.053	0.047	0.198	0.06	0	0	0	0	0	0	0	0
IS4	0	0	0	0	0	0.418	0.53	0.524	0.383	0.387	0	0	0	0	0	0	0	0
IS5	0	0	0	0	0	0.317	0.216	0.247	0.215	0.366	0	0	0	0	0	0	0	0
MC1	0.03	0.199	0.221	0.18	0.192	0.682	0.073	0.13	0.064	0.052	0.333	0.221	0.206	0.258	0.24	0.18	0.219	0.196
MC2	0.402	0.239	0.182	0.219	0.211	0.085	0.571	0.193	0.09	0.126	0.266	0.187	0.206	0.198	0.22	0.21	0.213	0.289
MC3	0.024	0.106	0.166	0.157	0.146	0.073	0.155	0.455	0.07	0.06	0.106	0.164	0.161	0.127	0.142	0.161	0.142	0.143
MC4	0.459	0.237	0.269	0.269	0.195	0.153	0.146	0.124	0.673	0.178	0.075	0.241	0.233	0.151	0.199	0.276	0.221	0.204
MC5	0.086	0.218	0.161	0.175	0.256	0.006	0.055	0.098	0.103	0.584	0.22	0.187	0.194	0.266	0.198	0.174	0.205	0.168
DA1	0	0	0	0	0	0.175	0.226	0.028	0.098	0.228	0.655	0.029	0.053	0.037	0	0	0	0
DA2	0	0	0	0	0	0.225	0.218	0.047	0.125	0.116	0.076	0.629	0.028	0.062	0	0	0	0
DA3	0	0	0	0	0	0.181	0.203	0.544	0.296	0.228	0.187	0.224	0.776	0.166	0	0	0	0
DA4	0	0	0	0	0	0.418	0.353	0.38	0.481	0.427	0.081	0.118	0.144	0.735	0	0	0	0
OM1	0.253	0.162	0.16	0.186	0.124	0	0	0	0	0	0.115	0.189	0.225	0.169	0.691	0.073	0.115	0.071
OM2	0.213	0.429	0.29	0.328	0.448	0	0	0	0	0	0.497	0.449	0.346	0.513	0.16	0.7	0.145	0.197
OM3	0.244	0.057	0.16	0.214	0.172	0	0	0	0	0	0.184	0.038	0.076	0.004	0.032	0.104	0.636	0.034
OM4	0.289	0.352	0.39	0.272	0.255	0	0	0	0	0	0.203	0.324	0.353	0.314	0.118	0.122	0.104	0.698

Table 10 Weighted super matrix

	IS1	IS2	IS3	IS4	IS5	RU1	RU2	RU3	RU4	RU5	DA1	DA2	DA3	DA4	OM1	OM2	OM3	OM4
IS1	0	0	0	0	0	0.055	0.022	0.058	0.052	0.051	0	0	0	0	0	0	0	0
IS2	0	0	0	0	0	0.018	0.045	0.003	0.016	0.011	0	0	0	0	0	0	0	0
IS3	0	0	0	0	0	0.016	0.018	0.016	0.066	0.02	0	0	0	0	0	0	0	0
IS4	0	0	0	0	0	0.139	0.177	0.175	0.128	0.129	0	0	0	0	0	0	0	0
IS5	0	0	0	0	0	0.106	0.072	0.082	0.072	0.122	0	0	0	0	0	0	0	0
MC1	0.015	0.1	0.111	0.09	0.096	0.227	0.024	0.043	0.021	0.017	0.111	0.074	0.069	0.086	0.12	0.09	0.11	0.098
MC2	0.201	0.119	0.091	0.109	0.105	0.028	0.19	0.064	0.03	0.042	0.089	0.062	0.069	0.066	0.11	0.105	0.106	0.145
MC3	0.012	0.053	0.083	0.079	0.073	0.024	0.052	0.152	0.023	0.02	0.035	0.055	0.054	0.042	0.071	0.081	0.071	0.072
MC4	0.23	0.119	0.134	0.134	0.098	0.051	0.049	0.041	0.224	0.059	0.025	0.08	0.078	0.05	0.1	0.138	0.111	0.102
MC5	0.043	0.109	0.081	0.088	0.128	0.002	0.018	0.033	0.034	0.195	0.073	0.062	0.065	0.089	0.099	0.087	0.102	0.084
DA1	0	0	0	0	0	0.058	0.075	0.009	0.033	0.076	0.218	0.01	0.018	0.012	0	0	0	0
DA2	0	0	0	0	0	0.075	0.073	0.016	0.042	0.039	0.025	0.21	0.009	0.021	0	0	0	0
DA3	0	0	0	0	0	0.06	0.068	0.181	0.099	0.076	0.062	0.075	0.259	0.055	0	0	0	0
DA4	0	0	0	0	0	0.139	0.118	0.127	0.16	0.142	0.027	0.039	0.048	0.245	0	0	0	0
OM1	0.127	0.081	0.08	0.093	0.062	0	0	0	0	0	0.038	0.063	0.075	0.056	0.345	0.037	0.057	0.036
OM2	0.106	0.215	0.145	0.164	0.224	0	0	0	0	0	0.166	0.15	0.115	0.171	0.08	0.35	0.072	0.099
OM3	0.122	0.029	0.08	0.107	0.086	0	0	0	0	0	0.061	0.013	0.025	0.001	0.016	0.052	0.318	0.017
OM4	0.145	0.176	0.195	0.136	0.128	0	0	0	0	0	0.068	0.108	0.118	0.105	0.059	0.061	0.052	0.349

Table 11 Limit matrix

	IS1	IS2	IS3	IS4	IS5	RU1	RU2	RU3	RU4	RU5	DA1	DA2	DA3	DA4	OM1	OM2	OM3	OM4
IS1	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
IS2	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
IS3	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
IS4	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
IS5	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
MC1	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081
MC2	0.091	0.091	0.091	0.091	0.091	0.09	0.091	0.091	0.091	0.091	0.09	0.091	0.091	0.091	0.09	0.09	0.09	0.091
MC3	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
MC4	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.098	0.099	0.099	0.099
MC5	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073
DA1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
DA2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
DA3	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
DA4	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
OM1	0.05	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.05	0.049	0.05	0.049	0.05	0.049
OM2	0.103	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.103	0.104	0.103	0.104
OM3	0.036	0.036	0.036	0.036	0.036	0.035	0.036	0.035	0.035	0.036	0.036	0.035	0.035	0.035	0.035	0.036	0.036	0.035
OM4	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078

References

Adinolfi, C., Bassiouni, D., Lauritzsen, H. F., & Williams, H. R. (2005). *Humanitarian response review: An independent report*. New York: UN.
Altay, N., & Labonte, M. (2014). Challenges in humanitarian information management and exchange: Evidence from Haiti. *Disasters, 38*(s1), S50–S72.
Altay, N., & Pal, R. (2014). Information diffusion among agents: Implications for humanitarian operations. *Production and Operations Management, 23*(6), 1015–1027.
Anaya-Arenas, A. M., Renaud, J., & Ruiz, A. (2014). Relief distribution networks: A systematic review. *Annals of Operations Research, 223*(1), 53–79.
Apte, A. (2009). Humanitarian logistics: A new field of research and action. *Foundations and Trends® in Technology, Information and Operations Management*, *3*(1), 1–100.
Balcik, B., Beamon, B. M., Krejci, C. C., Muramatsu, K. M., & Ramirez, M. (2010). Coordination in humanitarian relief chains: Practices, challenges and opportunities. *International Journal of Production Economics, 126*(1), 22–34.
Banomyong, R., Varadejsatitwong, P., & Oloruntoba, R. (2017). A systematic review of humanitarian operations, humanitarian logistics and humanitarian supply chain performance literature 2005 to 2016. *Annals of Operations Research*. https://doi.org/10.1007/s10479-017-2549-5.
Büyüközkan, G., & Çifçi, G. (2012). A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. *Expert Systems with Applications, 39*(3), 3000–3011.
Büyüközkan, G., & Öztürkcan, D. (2010). An integrated analytic approach for Six Sigma project selection. *Expert Systems with Applications, 37*(8), 5835–5847.
Chang, B., Chang, C. W., & Wu, C. H. (2011). Fuzzy DEMATEL method for developing supplier selection criteria. *Expert systems with Applications*, *38*(3), 1850–1858.
Chen, J. K., & Chen, I. S. (2010). Using a novel conjunctive MCDM approach based on DEMATEL, fuzzy ANP, and TOPSIS as an innovation support system for Taiwanese higher education. *Expert Systems with Applications, 37*(3), 1981–1990.
Chen, F. H., Hsu, T. S., & Tzeng, G. H. (2011). A balanced scorecard approach to establish a performance evaluation and relationship model for hot spring hotels based on a hybrid MCDM model combining DEMATEL and ANP. *International Journal of Hospitality Management, 30*(4), 908–932.
Chia, E. (2007). Engineering disaster relief. *IEEE Technology and Society Magazine, 26*(3), 24–29.
Comfort, L. K. (2007). Crisis management in hindsight: Cognition, communication, coordination, and control. *Public Administration Review, 67*(s1), 189–197.
Davis, L. B., Samanlioglu, F., Qu, X., & Root, S. (2013). Inventory planning and coordination in disaster relief efforts. *International Journal of Production Economics, 141*(2), 561–573.
Datta, S., Samantra, C., Sankar Mahapatra, S., Mandal, G., & Majumdar, G. (2013). Appraisement and selection of third party logistics service providers in fuzzy environment. *Benchmarking: An International Journal*, *20*(4), 537–548.
Day, J. M., Melnyk, S. A., Larson, P. D., Davis, E. W., & Clay Whybark, D. (2012). Humanitarian and disaster relief supply chains: A matter of life and death. *Journal of Supply Chain Management, 48*(2), 21–36.
Deb, S. K., Bhattacharyya, B., & Sorkhel, S. K. (2002). Material handling equipment selection by fuzzy multi-criteria decision making methods. In *AFSS international conference on fuzzy systems* (pp. 99–105). Heidelberg: Springer.
Dubey, R., Altay, N., & Blome, C. (2017). Swift trust and commitment: The missing links for humanitarian supply chain coordination? *Annals of Operations Research*. https://doi.org/10.1007/s10479-017-2676-z.
Ergun, Ö., Gui, L., Heier Stamm, J. L., Keskinocak, P., & Swann, J. (2014). Improving humanitarian operations through technology-enabled collaboration. *Production and Operations Management, 23*(6), 1002–1014.
Ertem, M., Buyurgan, N., & Pohl, E. (2012). Using announcement options in the bid construction phase for disaster relief procurement. *Socio-Economic Planning Sciences, 46*(4), 306–314.
Fritz, C. E., & Mathewson, J. H. (1957). Convergent behavior: A disaster control problem. Special report for the committee on disaster studies. Disaster study (Vol. 9, p. 476). N. R. C. National Academy of Sciences.
Gabus, A., & Fontela, E. (1973). *Perceptions of the world problematique: Communication procedure, communicating with those bearing collective responsibility*. Geneva: Battelle Geneva Research Center.
Gölcük, İ., & Baykasoğlu, A. (2016). An analysis of DEMATEL approaches for criteria interaction handling within ANP. *Expert Systems with Applications, 46,* 346–366.
Gonzalez, R. A. (2010). Developing a multi-agent system of a crisis response organization. *Business Process Management Journal, 16*(5), 847–870.
Gupta, R., Sachdeva, A., & Bhardwaj, A. (2012). Selection of logistic service provider using fuzzy PROMETHEE for a cement industry. *Journal of Manufacturing Technology Management*, *23*(7), 899–921.

Haleh, H., & Hamidi, A. (2011). A fuzzy MCDM model for allocating orders to suppliers in a supply chain under uncertainty over a multi-period time horizon. *Expert Systems with Applications, 38*(8), 9076–9083.
He, T., Ho, W., Lee Ka Man, C., & Xu, X. (2012). A fuzzy AHP based integer linear programming model for the multi-criteria transshipment problem. *The International Journal of Logistics Management, 23*(1), 159–179.
Heaslip, G., Sharif, A. M., & Althonayan, A. (2012). Employing a systems-based perspective to the identification of inter-relationships within humanitarian logistics. *International Journal of Production Economics, 139*(2), 377–392.
Holguín-Veras, J., Jaller, M., Van Wassenhove, L. N., Pérez, N., & Wachtendorf, T. (2012). Material convergence: Important and understudied disaster phenomenon. *Natural Hazards Review, 15*(1), 1–12.
Holguín-Veras, J., Pérez, N., Ukkusuri, S., Wachtendorf, T., & Brown, B. (2007). Emergency logistics issues affecting the response to Katrina: A synthesis and preliminary suggestions for improvement. *Transportation Research Record: Journal of the Transportation Research Board, 2022,* 76–82.
Holguín-Veras, J., Taniguchi, E., Jaller, M., Aros-Vera, F., Ferreira, F., & Thompson, R. G. (2014). The Tohoku disasters: Chief lessons concerning the post disaster humanitarian logistics response and policy implications. *Transportation Research Part A: Policy and Practice, 69,* 86–104.
Hossain, L., & Uddin, S. (2012). Design patterns: Coordination in complex and dynamic environments. *Disaster Prevention and Management: An International Journal, 21*(3), 336–350.
Hristidis, V., Chen, S. C., Li, T., Luis, S., & Deng, Y. (2010). Survey of data management and analysis in disaster situations. *Journal of Systems and Software, 83*(10), 1701–1714.
Hwang, C. L., & Yoon, K. (1981). *Multiple attribute decision making, methods and applications* (Vol. 186). New York: Springer.
Jabbour, C. J. C., Sobreiro, V. A., de Sousa Jabbour, A. B. L., de Souza Campos, L. M., Mariano, E. B., & Renwick, D. W. S. (2017). An analysis of the literature on humanitarian logistics and supply chain management: Paving the way for future studies. *Annals of Operations Research*, 1–19.
Jahre, M., & Jensen, L. (2010). Coordination in humanitarian logistics through clusters. *International Journal of Physical Distribution & Logistics Management, 40*(8/9), 657–674.
Kamradt-Scott, A. (2016). WHO's to blame? The World Health Organization and the 2014 Ebola outbreak in West Africa. *Third World Quarterly, 37*(3), 401–418.
Kayikci, Y. (2010). A conceptual model for intermodal freight logistics centre location decisions. *Procedia-Social and Behavioral Sciences, 2*(3), 6297–6311.
Kent, R. C. (2004). International humanitarian crises: two decades before and two decades beyond. *International Affairs*, *80*(5), 851–869.
Kovács, G., & Spens, K. M. (2011). Trends and developments in humanitarian logistics-a gap analysis. *International Journal of Physical Distribution & Logistics Management, 41*(1), 32–45.
Leiras, A., De Brito Jr, I., Queiroz Peres, E., Rejane Bertazzo, T., & Tsugunobu Yoshida Yoshizaki, H. (2014). Literature review of humanitarian logistics research: Trends and challenges. *Journal of Humanitarian Logistics and Supply Chain Management, 4*(1), 95–130.
Li, Y., Liu, X., & Chen, Y. (2011). Selection of logistics center location using Axiomatic Fuzzy Set and TOPSIS methodology in logistics management. *Expert Systems with Applications, 38*(6), 7901–7908.
Moshtari, M. (2016). Inter-organizational fit, relationship management capability, and collaborative performance within a humanitarian setting. *Production and Operations Management, 25*(9), 1542–1557.
Olaogbebikan, J. E., & Oloruntoba, R. (2017). Similarities between disaster supply chains and commercial supply chains: A SCM process view. *Annals of Operations Research*. https://doi.org/10.1007/s10479-017-2690-1.
Oloruntoba, R. (2005). A wave of destruction and the waves of relief: Issues, challenges and strategies. *Disaster Prevention and Management: An International Journal, 14*(4), 506–521.
Opricovic, S., & Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research, 156*(2), 445–455.
Paksoy, T., Pehlivan, N. Y., & Kahraman, C. (2012). Organizational strategy development in distribution channel management using fuzzy AHP and hierarchical fuzzy TOPSIS. *Expert Systems with Applications, 39*(3), 2822–2841.
Saaty, T. L. (1980). *The analytic hierarchy process*. New York: McGraw-Hill.
Saaty, T. L. (1996). *Multi-criteria decision making*. Pittsburgh: The Analytic Hierarchy Process.
Sawicka, H., & Zak, J. (2014). Ranking of distribution system's redesign scenarios using stochastic MCDM/A procedure. *Procedia-Social and Behavioral Sciences, 111,* 186–196.
Schulz, S. F., & Blecken, A. (2010). Horizontal cooperation in disaster relief logistics: Benefits and impediments. *International Journal of Physical Distribution & Logistics Management, 40*(8/9), 636–656.
Seybolt, T. B. (2009). Harmonizing the humanitarian aid network: Adaptive change in a complex system. *International Studies Quarterly, 53*(4), 1027–1050.

Shen, Y. C., Lin, G. T., & Tzeng, G. H. (2011). Combined DEMATEL techniques with novel MCDM for the organic light emitting diode technology selection. *Expert Systems with Applications, 38*(3), 1468–1481.
Sheppard, A., Tatham, P., Fisher, R., & Gapp, R. (2013). Humanitarian logistics: Enhancing the engagement of local populations. *Journal of Humanitarian Logistics and Supply Chain Management, 3*(1), 22–36.
Stephenson, M., Jr. (2005). Making humanitarian relief networks more effective: Operational coordination, trust and sense making. *Disasters, 29*(4), 337–350.
Tatham, P., & Kovács, G. (2010). The application of "swift trust" to humanitarian logistics. *International Journal of Production Economics, 126*(1), 35–45.
Tatham, P., & Spens, K. (2011). Towards a humanitarian logistics knowledge management system. *Disaster Prevention and Management: An International Journal, 20*(1), 6–26.
Telford, John. (2006). *Joint evaluation of the international response to the Indian Ocean tsunami: Synthesis report*. London: Tsunami Evaluation Coalition.
Tomasini, R. M., & Van Wassenhove, L. N. (2009). From preparedness to partnerships: Case study research on humanitarian logistics. *International Transactions in Operational Research, 16*(5), 549–559.
Tseng, M. L. (2009). Application of ANP and DEMATEL to evaluate the decision-making of municipal solid waste management in Metro Manila. *Environmental Monitoring and Assessment, 156*(1), 181–197.
Tseng, M. L. (2011). Using a hybrid MCDM model to evaluate firm environmental knowledge management in uncertainty. *Applied Soft Computing, 11*(1), 1340–1352.
Tuzkaya, G., & Gülsün, B. (2008). Evaluating centralized return centers in a reverse logistics network: An integrated fuzzy multi-criteria decision approach. *International Journal of Environmental Science and Technology, 5*(3), 339–352.
Van Wassenhove, L. N. (2006). Blackett Memorial Lecture -Humanitarian aid logistics: Supply chain management in high gear. *Journal of the Operational Research Society, 57*(5), 475–489.
Wu, W. W. (2008). Choosing knowledge management strategies by using a combined ANP and DEMATEL approach. *Expert Systems with Applications, 35*(3), 828–835.
Yates, D., & Paquette, S. (2011). Emergency knowledge management and social media technologies: A case study of the 2010 Haitian earthquake. *International Journal of Information Management, 31*(1), 6–13.
Zetter, R. (1995). Incorporation and exclusion: The life cycle of Malawi's Refugee assistance program. *World Development, 23*(10), 1653–1667.
Zhou, Q., Huang, W., & Zhang, Y. (2011). Identifying critical success factors in emergency management using a fuzzy DEMATEL method. *Safety Science, 49*(2), 243–252.

Affiliations

Lijo John[1] · Anand Gurumurthy[1] · Gunjan Soni[2] · Vipul Jain[3]

Lijo John
lijoj06fpm@iimk.ac.in

Anand Gurumurthy
anandg@iimk.ac.in

Gunjan Soni
gsoni.mech@mnit.ac.in

1 Quantitative Methods and Operations Management (QM and OM) Area, Indian Institute of Management Kozhikode (IIMK), IIMK Campus P.O., Kunnamangalam, Kozhikode, Kerala 673570, India

2 Mechanical Engineering Department, Malaviya National Institute of Technology, Jaipur, JawaharLal Nehru Marg, Malaviya Nagar, Jaipur, India

3 School of Management, Victoria Business School, Victoria University of Wellington, 23, LambtonQuay, Pipitea Campus, PO Box 600, Wellington 6140, New Zealand