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

A fuzzy AHP-TOPSIS approach to supply partner selection in continuous aid humanitarian supply chains

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Abstract
The selection of suitable supply partners is a strategic issue for managers working in humanitarian operations and has received little attention in the literature. In humanitarian operations, complexity characterizes the continuous-aid procurement operations, and the selection criteria can differ from those used in commercial supply chain settings. This paper advances knowledge by introducing a supply partner selection framework for *continuous-aid* procurement. A proposed multi-criteria decision-making model uses selection criteria attributes verified by the extant literature and by field experts. A fuzzy *Analytic Hierarchy Process* is then used to compute criterion weights, and a fuzzy *Technique for Order Performance by Similarity to Ideal Solution* is used to rank supply partner alternatives. Even with elevated levels of subjectivity, these techniques enable humanitarian operation stakeholders to select the best supply partner effectively. An actual case illustrates how the proposed framework efficiently identifies the most suitable continuous-aid supply partner for the prevailing situation.

Keywords Supplier selection · AHP · TOPSIS · Humanitarian supply chain · Humanitarian logistics · Multi-criteria decision-making (MCDM) · Disaster relief chain

1 Introduction

Humanitarian organizations must overcome many challenges to dispatch suitable relief materials with agility (Van Wassenhove 2006; Kovács and Spens 2007; Duran et al. 2013). As part of an effort to effectively manage these challenges, there is a growing operational focus on pre-positioning logistics (Barbarosoglu and Arda 2004; Özdamar et al. 2004; Yi and Özdamar 2007; Özdamar and Ertem 2015; Ahmadi et al. 2015; Victoria et al. 2015; Chen et al. 2017) and inventory management (Beamon and Kotleba 2006; Davis et al. 2013; He and Zhuang 2016; Richardson et al. 2016). These studies are essential for identifying the most effective and efficient relief management strategies for a set of circumstances (Van Wassenhove 2006). Researchers are also exploring the dynamics of sourcing and coordination in complex, uncertain humanitarian supply chain (HSC) environments (Kovács and Spens 2009; Balcik et al. 2010; Duran et al. 2013; Iakovou et al. 2014), which can involve significant quantities, low

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prices, and minimal quality expectations throughout the entire chain of operations (Falasca and Zobel 2011).

Patterns in humanitarian procurement operations may vary according to the degree of responsiveness required and the positioning of materials in the supply chain (Tatham and Kovács 2010). Associated procurement activities typically divide into *development aid* and *humanitarian relief* (Falasca and Zobel 2011). Development aid procurement primarily focuses on the movement of materials into the relief area, at which time stakeholders like non-governmental organizations (NGOs) are continually sourcing as a vital part of the relief and developmental activities, and are liaising with donors (Byman et al. 2000). Humanitarian domain practitioners define such activities as *continuous-aid*, a stage which has only recently been recognized as an integral part of a relief program (Kovács and Spens 2009). The relief procurement process mainly focuses on activities that are needed to save lives; responding to disaster intensity by obtaining relatively inexpensive items from sources close to the disaster site (Falasca and Zobel 2011). A large organization like the *Red Cross* may trigger a specific relief program when a disaster strikes a designated area, *humanitarian relief procurem*ent supply chains can be leaner than their *continuous-aid* procurement counterparts.

A humanitarian organization will typically partner with selected donors to collect relief materials, such as tents and clothing, from pre-positioned areas under an operating framework agreement (Balcik and Ak 2014), requiring effective procurement and coordination mechanisms with supply partners. Such continuous-aid activities have motivated relief agencies to harness scientific methods for considerations around sourcing, distribution and logistics (Ertem et al. 2010; Venkatesh et al. 2014). In the wake of the overwhelming abundance of qualitative studies, researchers have recently turned their attention to scientific methods to better understand the rationale behind procurement mechanisms (Iakovou et al. 2014). Also, even though abundant literature exists on commercial supply networks (Balcik and Ak 2014) little has been written on supply partner selection from the perspective of humanitarian organisations.

The extant literature is yet to report a comprehensive continuous-aid supply partner selection framework. The objective of this study is to propose and evaluate a new supply partner evaluation model that can assist humanitarian firms when they are selecting their *continuous aid* supply partners. The inherent uncertainty in the humanitarian relief domain means that the selection parameters can be different to commercial or *disaster-triggered* procurement activities. For example, the model must take into account stakeholder subjectivity. Hence, the proposed supplier evaluation comprises a fuzzy *Analytic Hierarchy Process (AHP)* to establish the weights of preferences, which is followed by a fuzzy *Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)* to rate the performance of feasible alternatives. Performance, expressed in linguistic values, is parameterized using triangular fuzzy numbers (Sun 2010). Thus, the model deals with a Multi-Criteria Decision-making (MCDM) problem and contemplates subjective criteria in the selection process (Dağdeviren et al. 2009).

The absence of a comprehensive *continuous-aid* supply partner selection framework means that aid organizations often struggle to engage partners with international levels of humanitarian supply chain performance. Thus, evaluation of the proposed model draws on expert feedback from those who are engaged in managing partner relationships in real humanitarian networks with *continuous-aid* procurement programs.

This study significantly advances knowledge about procurement by humanitarian organizations. It is believed to be the first study on supply partner evaluation in *continuous-aid* humanitarian supply chains which uses an MCDM technique to classify discrete partner selection criteria and which also compares them with those of commercial contexts. The proposed structured (fuzzy AHP and TOPSIS) selection process framework can help humanitarian supply chain operators to more effectively select the best supply partner, even under conditions of elevated subjectivity.

The paper is structured as follows. The next section reviews the humanitarian supply chain's procurement literature and related supply partner selection methods. The review is followed by a description of a two-stage process for developing a humanitarian supply partner selection framework, which involves identifying suitable parameters from the literature and humanitarian expert stakeholders, followed by a fuzzy AHP and TOPSIS being conducted. A case study is presented to illustrate the method, which is then followed by conclusions, study limitations, practical implications, and suggested research directions.

2 Literature review

The following systematic review of the literature utilized the methodology for developing evidence-informed management knowledge described by Tranfield et al. (2003).

2.1 Humanitarian supply process

The priority of humanitarian organizations is to coordinate different stakeholders and achieve visibility of aid materials for the needy. Humanitarian supply chains involve complex operations, and the associated risks and uncertainties call for flexibility in design and operation (Thomas and Mizushima 2005). Humanitarian operations also frequently exhibit reduced control of the costs and quality of supply materials compared to a typical commercial supply chain (Oloruntoba and Gray 2006). Zobel (2011) attributes 65% of relief operations costs to disaster preparedness, planning, procurement, and transportation, including customs clearance and tracking (Thomas and Kopczak 2005). In contrast with regular business environments, humanitarian marketing activities mainly focus on persuading donors to participate in relief activities.

Renewed interest in the dynamics of aid response is primarily attributed to the increased frequency of disasters, differing stakeholder perspectives, and the expansion of domain boundaries (Duran et al. 2013). The humanitarian procurement process aims to acquire sufficient supplies to meet relief needs (PAHO 2001; Fritz Institute 2005; Pettit and Beresford 2009; Schätter et al. 2015) and to provide assistance in the form of food, shelter, medicine and essential supplies (Ozdamar 2011). Management systems have implications for the resilience and effectiveness of relief supply chains (Oloruntoba and Gray 2006; Venkatesh et al. 2014). Relief agencies need access to responsive systems that meet the operational needs of a challenging, uncertain environment (Charles et al. 2010; Schulz and Blecken 2010).

Typically, relief initiatives for alleviating human suffering deploy in four main stages: mitigation, preparedness (both stages constituting pre-disaster preparation), response, and recovery (post-disaster activity) (Altay and Green 2006). For example, Van Wassenhove (2006) reports a time-based classification of disaster responses and describes different patterns of sourcing and coordination among international suppliers.

There have been very few investigations of the humanitarian supply partner selection process (Balcik and Ak 2014), although some studies have illustrated the competitive bidding models commonly used (Ertem et al. 2010; Bagchi et al. 2011). For example, it has been shown that those organizations which increase their focus on continuous collection, or on development aid procurement activities, become more adept at responding to emergen-

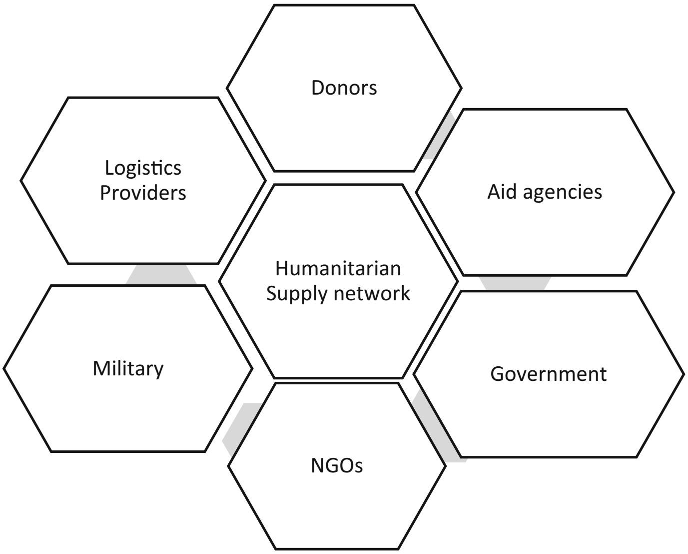

Fig. 1 Stakeholders in the humanitarian supply system. (*Source*: adapted from Kovács and Spens 2007)

cies (Taupiac 2001; Falasca and Zobel 2011; Duran et al. 2013). Tatham and Pettit (2010) endorse the imperative of supply network management in relief logistics chains. Selecting partners for a humanitarian network can be a challenging multi-decision-maker process and, in contrast with commercial operations, the procurement decisions may be mainly based on consideration of historical data concerning the magnitude and types of disasters previously experienced by that region (Duran et al. 2013).

At the onset of a disaster, the humanitarian aid supply situation is almost always a mismatch between demand and supply, which forces humanitarian organizations to adopt a *continuous-aid* procurement program even though inventory stockpiling could be a significant concern (Iakovou et al. 2014). The humanitarian procurement/supply process has various stakeholders, among whom donors, NGOs, local bodies and aid recipients are the most important (John et al. 2012). Figure 1, adapted from Kovács and Spens (2007), indicates the primary stakeholders in such a supply network. Governmental organizations exercise most control over the entire spectrum of pre- and post-disaster responses. Whether national or international, non-governmental organizations (NGOs) are also essential and are mostly involved in the mitigation phase, sending the right materials to affected areas. The *International Federation of Red Cross (IFRC), World Vision, World Food Program (WFP), CARE* and *OXFAM* are perhaps the most notable international NGOs and maintain their own humanitarian operations. They may also collaborate with local suppliers to continuously mobilize resources, although this can be more costly, less durable, or involve long lead times for development aid or humanitarian relief (Akkihal 2006). NGOs may also be responsible for the last-mile delivery (Duran et al. 2013).

Humanitarian organizations typically partner with selected donors to collect materials in pre-positioned areas under an operating framework agreement (Balcik and Ak 2014), thereby establishing long-term associations/partnerships with their regular material supplier stakeholders (Balcik and Ak 2014). They may also use local sources, cash components, and community approaches for shelter and clothing (Kovács and Spens 2009).

Once collected, supplies can be used in three main ways: (a) pre-positioning of materials for predicted disasters, (b) continuous relief activities, and (c) post-disaster management (Duran et al. 2013). While pre-positioning of materials will increase responsiveness, it limits the amount available to humanitarian organizations to spend on warehouses and distribution centres (Balcik and Beamon 2008). This trade-off is a critical factor in the overall procurement decision. *Continuous-aid* procurement in humanitarian activities calculate overall demand and initiate procurement locally and globally, depending on availability, preferences, cost and many other factors (Balcik and Beamon 2008; Blecken 2010; Falasca and Zobel 2011). Although non-consumable items (such as tents, medical kits, relief equipment, and operational materials) tend to be sourced globally with the long-term understanding of the supply partners, it is sometimes judged preferable to source culturally-acceptable relief items from within the local area (Duran et al. 2013).

2.2 Partner selection

Supply partner selection is a strategic decision as the desired outcome of continuous-aid humanitarian supplies is long-term sustainability (Saksrisathaporn et al. 2016). The commercial supply management and partner selection criteria described in the literature are less relevant to humanitarian networks, not least because their relative importance changes over time as the emergency response progresses (Gutjahr and Nolz 2016). The quantity and quality of available data also evolve with the process, hence supply chain priorities continually change and call for humanitarian supply chain agility (Saksrisathaporn et al. 2016).

Multi-criteria selection studies in humanitarian studies have recently gained in popularity due to their practical relevance. El-Anwar et al. (2009) addressed an MCDM solution to humanitarian housing projects and, more recently, Nappi and Souza (2015) and Bozorgi-Amiri and Asvadi (2015) applied MCDM to study the issue of shelter location. Gutjahr and Nolz (2016) endorse the need for more MCDM techniques in the humanitarian-aid domain, to address the challenge of stakeholders with different missions and interests. Consequently, this study utilizes AHP and TOPSIS (MCDM) techniques to explore partner selection in a *continuous-aid* humanitarian supply chain.

A variety of techniques, including MCDM, have been proposed since Dickson (1966) reported his pioneering work on assessing desirable partner characteristics (Chai et al. 2013). As noted above, because the business environment within which humanitarian supply chains operate changes, as a result of many factors, solving real-time problems with MCDM involves qualitative and quantitative factors with multiple objectives (Bhutta and Huq 2002; Çebi and Bayraktar 2003; Ramanathan 2007; Chai et al. 2013). Recent studies acknowledge the importance of MCDM to explore issues related to humanitarian supply chains, however Gultjahr and Nolz (2016) highlight the difficulty of bringing such techniques closer to practical application (Celik et al. 2014; Celik and Gumus 2015; Abidi et al. 2015; Roh et al. 2015; Ju et al. 2015). MCDM can help practitioners to appreciate the trade-offs, priority factors, multiple conflicting goals and supplier strengths and weaknesses, thereby improving humanitarian supplier selection decisions (Wang et al. 2009; Shaw et al. 2012; Bozorgi-Amiri et al. 2013). Table 1 illustrates a broad range of MCDM techniques (Loken 2007; Venkatesh et al. 2015). There are now more than 80 techniques and hybrid forms available (Shyur and Shih 2006).

MCDM techniques have begun to emerge which consider uncertainty and complex situations in business contexts (de Boer et al. 1998; Shyur and Shih 2006; Loken 2007; Ho Oh et al. 2010), including a growing interest in hybridized MCDM techniques (Chiu et al. 2013;

Table 1 MCDM model classifications. (Adapted from Loken 2007; Venkatesh et al. 2015)

Model type	Representative technique
Value measurement models	Analytic Hierarchy Process (AHP) (Saaty 1990) Multi-attribute utility theory (Keeney and Raiffa 1976)
Goal, aspiration, and reference level models	Goal programming (Ignizio 1976) Technique for order of preference by similarity to ideal solution (TOPSIS) (Hwang and Yoon 1981)
Outranking techniques	Elimination and choice expressing reality (ELECTRE) (Roy 1968) Preference ranking organization method for enrichment of evaluations (PROMETHEE) (Brans and Vincke 1985) Decision-making trial and evaluation laboratory (DEMATEL) (Gabus and Fantela 1972) Simple multi-attribute rating technique (SMART) (Belton 1986)

Avikal et al. 2014; Tadic et al. 2014; Tsai et al. 2014; Zhao and Guo 2014; Bai et al. 2015; Chithambaranathan et al. 2015; Tsui et al. 2015; Sangiah et al. 2015; Liou et al. 2016).

Multi-attribute utility selection mechanisms such as *AHP* focus on utility values that represent the degree of preference for each alternative and clarify the alternatives through ranking (Saaty 1990). They also use pairwise comparisons, drawing on expert judgements to handle intangible attributes (Saaty 1990; Chai et al. 2013).

TOPSIS is a compromise model that is widely used for supplier selection. It achieves solutions close to the ideal via mutual concessions, using linear normalization, and removing the criteria unit functions (Chai et al. 2013). However, such conventional MCDM techniques do not effectively handle linguistic assessments (Shyur and Shih 2006; Shukla et al. 2014).

Recently, studies have endorsed the use of combined *fuzzy AHP* and *fuzzy TOPSIS* techniques for solving business issues in uncertain environments (Aktan and Tosun 2013; Samvedi et al. 2013; Cevik Onar et al. 2014; Mandic et al. 2014; Taylan et al. 2014; Junior et al. 2014; Metaxas et al. 2016; Jain et al. 2016). Zeydan et al. (2011) summarize the advantages and rationale for the use of a hybrid technique in which *fuzzy AHP* calculations deduce the weights, via qualitative and quantitative methods, which are the inputs to the *fuzzy TOPSIS* model. The weights evaluated with the *fuzzy AHP* technique are subjective (sourced from experts), and the *fuzzy TOPSIS* model uses them to rank the supplier pool on overall performance. *TOPSIS* also identifies the solution which is closest to the positive ideal solution and farthest from the negative one. The integrated AHP and TOPSIS approach of transforming qualitative data into their equivalent quantitative measures is recognized as one of the most efficient and preferred decision-making methods (Taylan et al. 2014). Saksrisathaporn et al. (2016) recently used this approach for humanitarian-operation life-cycle integration studies.

In summary, despite its acknowledged importance, the literature on sourcing in humanitarian operations is rare and mostly reports qualitative research (Ertem et al. 2010; Falasca and Zobel 2011; Iakovou et al. 2014; Balcik and Ak 2014). Also, while ample research is available on relief coordination mechanisms (Balcik et al. 2010; Jahre and Jensen 2010; Davis et al. 2013; Zhan et al. 2014), supply partner selection in the preparedness and *continuous-aid* contexts appears to be absent in the literature.

3 Research method

In consideration of the preceding discussion, a three-stage process was used to develop a humanitarian supply partner selection framework, comprising:

1. Identification of candidate parameters from the literature and interaction with humanitarian operations stakeholder/operator experts;
2. Evaluation of candidate parameters;
3. Development of the framework using *fuzzy AHP* and *TOPSIS* analyses.

3.1 Identification of candidate parameters

A three-stage process was used to increase the validity of the research. First, a comprehensive list of candidate parameters for the model was identified from the literature. These attributes are not specific to relief activities (Beamon and Balcik 2008). Then, eight executives with senior roles in strategic decision-making, including partner selection, were consulted. Their feedback yielded six primary supply partner evaluation criteria (parameters) and 24 sub-criteria. Other experts from the humanitarian domain verified the parameters.

3.2 Evaluation of candidate parameters

The study of performance measurement in relation to relief or humanitarian supply chains is an emerging domain in supply chain research (Beamon and Balcik 2008) and the literature lacks a comprehensive framework for concurrently measuring the relevant factors. The complete list of identified supply partner evaluation attributes is shown in Table 2, together with their relevant sub-criteria. These primarily relate to logistics capability.

3.2.1 The humanitarian logistics performance (HLP) attribute

Many assessment frameworks (Schmitz and Platts 2004) assess the degree of external and internal integration as this is judged to be a measure of the supplier's ability to maintain the agreed level of performance (Gimenez and Ventura 2005).

Humanitarian organizations, and especially those which are UN based, tend to operate under their own rules and use unique systems to measure a partner's logistics performance (Beamon and Balcik 2008). Many are closely monitored for their ability to deliver the 'right' quantity of materials at the 'right' time to the right place at a certain cost. Because the materials collected need to be serviceable, supply partners are also expected to exhibit a degree of innovation and ability to introduce new, useful products from their stock of collected materials. Examples of this are when a supply partner converts used cartons into paper cups or creates napkins from surplus clothing.

3.2.2 The legal and governance (LG) attribute

Humanitarian relief operations have similarities with their commercial supply chain counterparts in needing to comply with legal frameworks. Supplies from various locations around the world may arrive at pre-positioned warehouses, creating potential legal and governance issues due to differences in national rules (Natarajarathinam et al. 2009). Hence, this attribute primarily relates to the importance to logistics capability of candidate supply partners regarding

Table 2 Supply partner attributes

Attribute	Sub-criterion
Humanitarian logistics performance (HLP) (Beamon and Balcik 2008)	Delivery performance (HLP1) Socio-economic impact (HLP2) Innovation (HLP3) Cost performance (HLP4)
Legal and governance (LG) (Natrajarathinam et al. 2009)	Global outreach (LG1) Compliance with standards and regulation (LG2) Organizational design (LG3) Internal processes (LG4) Framework and agreements (LG5)
Sustainable operations (S) (Foerstl et al. 2015)	Process adherence (S1) Risk management (S2) Supply chain design (S3) Awareness of stakeholders (S4)
Responsiveness (R) (Jahre et al. 2009; Tomasini and Van Wassenhove 2009)	Network management (R1) Transparency (visibility) (R2) Service capacity (R3) Lead-time management (R4)
Partnership strategy (PS) (Chandes and Paché 2010)	Long-term vision (PS1) Continuous improvement strategy (PS2) Sector-specific strategy (PS3) Coordination mechanisms (PS4)
Operational factors (supply chain relevance) (M) (Oloruntoba and Gray 2006)	Needs-based assessment (M1) Service portfolio (M2) Flexibility in service (M3)

their global outreach and ability to comply with, for example, global standards for packaging and product quality.

Organizational design and governance are also critical sub-criteria for the humanitarian chain operators due to the need for their operations to rapidly process information and be responsive and reliable (Wang and Wei 2007). The operators also value partners that control their internal operations and adhere to internal standards, since this assures *continuous-aid* process operators of a degree of consistency and control. A fruitful association also highly depends on there being standards in place which are agreeable to humanitarian chain operators and partners.

3.2.3 The sustainable operations (S) attribute

While profitability is a critical goal of commercial operations, it is not the only one (Hay et al. 2005). The heightened expectation of sustainable business practice has created pressure for sustainable sourcing and procurement (Foerstl et al. 2015), better care of the environment, and ethical treatment of employees (Kleindorfer et al. 2005). Such practices are assessed firstly by their sustainability at the process level of the environmental contribution and, secondly, by how well partners with a robust risk management agenda adhere to declared process capabilities while managing disaster interventions. This attribute also depends on how well potential humanitarian chain partners educate their stakeholders to adhere to agreed process standards that sustain overall business objectives (Wilhem et al. 2016).

3.2.4 The responsiveness (R) attribute

Although the concept of responsiveness is complex in humanitarian operations (Oloruntoba and Gray 2006), it is vital that potential partners be assessed for their ability to rapidly respond to 'customer' needs (Jahre et al. 2009). In a commercial setting, responsiveness is directly related to the satisfaction of customers, regarding the ability to meet expectations (Christopher and Towill 2000). Kovács and Tatham (2009) endorse the responsiveness requirement for humanitarain organizations and the pre-positioning process since network design profoundly impacts humanitarian firms that focus on node management and factor locations into their routing decisions (Eskigun et al. 2005; Javid and Azad 2010).

Service capacity is another integral element of humanitarian firms' responsiveness because deployment of permanent and temporary networks involves structured inventory decisions (Eskigun et al. 2005). Moreover, robust monitoring systems and information transparency between supply chain partners increases performance and reduces risk (Oloruntoba and Gray 2006), and many humanitarian organizations use integrated software for these purposes (Charles et al. 2010; Gatignon et al. 2010). Transparency makes lead times more manageable, increases the return on supply mechanisms (Tomasini and Van Wassenhove 2009), and enables postponement strategies to meet local requirements (Tomasini and Van Wassenhove 2009).

3.2.5 The partner strategy (PS) attribute

Ideally, every supply partner will have a long-term vision to participate in humanitarian operations (Chandes and Paché 2010) since this will impact all of the decisions around financial and network management. Similarly recognized as an essential characteristic is the pursuit of continuous improvement (Pettit and Beresford 2009). Having a sector-specific strategy means that a partner can sustain and increase service reliability, focusing on such operations as product collection, product management, new product development, transportation, packaging, warehousing, and distribution. The partner strategy is also strengthened by vertical or horizontal coordination mechanisms (Jahre et al. 2009; Tomasini and Van Wassenhove 2009), which is a challenging element in humanitarian operations given their inherent uncertainty (Kovács and Spens 2009).

3.2.6 The operational factors (M) attribute

The ability to perform a needs assessment is a foremost requirement (Tomasini and Van Wassenhove 2009) since a robust capability in this area empowers partners to forecast demand and mobilize resources (Oloruntoba and Gray 2006). The supply chain also becomes more agile by making the humanitarian operations leaner through waste reduction (Oloruntoba and Gray 2006; Kovács and Spens 2011). Typically, the partner's service portfolio reports the complete range of services, from manufacturing to trading, packaging, warehousing, and distribution.

As humanitarian organizations are inherently unpredictable, the final sub-criterion is partner flexibility (Oloruntoba and Gray 2006). Partners need to be able to quickly and easily modify their operations in light of disaster intensity, and delivery and material needs (Beamon and Balcik 2008). According to Slack (1991), such range and response flexibility can be readily assessed.

3.3 Development of the framework using fuzzy AHP and TOPSIS analyses

In choosing which analytical technique to use, the authors judged that an ideal MCDM procedure for supply partner selection would take account of attribute weightings and involve computational procedures which are suitable for non-specialist practitioners (Wang and Chang 2007).

AHP is a useful technique for determining the relative importance of system variables. When compared to *Analytic Network Process* (ANP), it is also easier to use and requires fewer pairwise comparison matrices (Harputlugil et al. 2011). Similarly, the TOPSIS approach is favored for being relatively easy to understand and compute, and for its ability to incorporate attribute weightings and determine the most optimal alternative (Wang and Chang 2007).

Fuzzy-based AHP is a sound choice for problems with few criteria and alternatives. Otherwise the number of pairwise comparisons increases significantly to become cumbersome (Mangla et al. 2015). Humanitarian chain partner selection frequently considers many criteria and alternatives (Shipley et al. 1991) and requires human bias and data ambiguity to be captured. These factors make the use of computationally-efficient fuzzy AHP-TOPSIS analysis very suitable for the supply partner selection problem, at least in comparison to AHP/fuzzy AHP techniques (Dagdeviren et al. 2009). The fuzzy combination enables human bias and data ambiguity to be captured (Zadeh 1965). Hence, fuzzy *Analytic Hierarchy Process (AHP)* was used to establish the weights of the humanitarian supply partner selection criteria, and fuzzy *Technique for Order Performance by Similarity to Ideal Solution* (TOPSIS) was used to efficiently select the best supply partner for relief organizations.

3.3.1 Fuzzy set theory

Decision-making from an organizational perspective is a complex process because there is often a lack of clarity in the data and a tendency for human bias. Notably, because humans prefer to make their judgments in linguistic terms, it is vital to transform those terms into specific computational values. The use of fuzzy set theory allows for human linguistic preferences while also transforming them into numerical values via fuzzy numbers. In fuzzy set theory, if a set of objects is clustered and represented by x, then x signifies a generic element with values $x_1, x_2, x_3 \ldots x_n$). In this situation, the fuzzy set a for this object set is given by $\{(x, \mu_A(x))|x \in X\}$ (Zimmermann 2011). Here, μ_A (x) signifies the membership function of this object set, belonging to the interval [0, 1]. Thus, fuzzy set theory provides information for evaluating decision problems in vague surroundings (Zadeh 1965). The present study uses triangular fuzzy numbers (TFN) (Zimmermann 2011). The membership function for the triangular fuzzy number (i, j, k) is constructed as shown in Fig. 2.

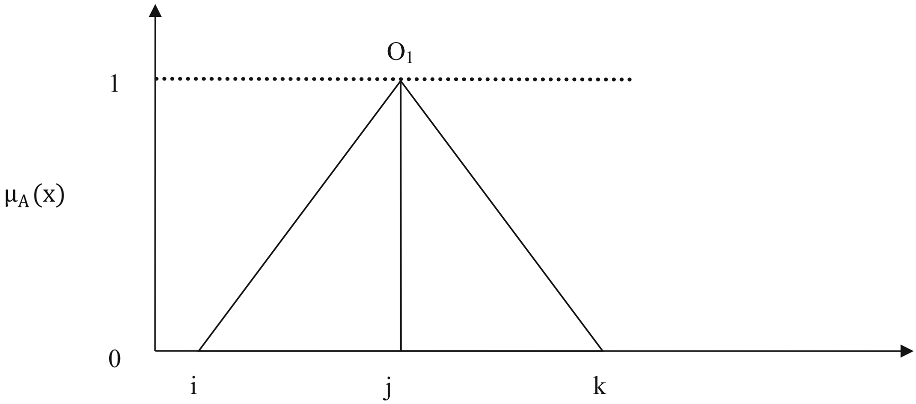

Fig. 2 Membership function for the triangular fuzzy number

The mathematical expression for μ_A (x) is provided in Eq. (1). The values (i, j, k) signify the lower, mean and upper bounds of the TFN. If $P_1 = (i, j, k)$ and $P_2 = (l, m, n,)$ are two TFNs, the algebraic operations for them are as follows:

$$P_1 + P_2 = (i, j, k) + (l, m, n) = (a + p, b + q, c + r)$$

$$P_1 - P_2 = (i, j, k) - (l, m, n) = (a - p, b - q, c - r)$$

$$P_1 \times P_2 = (i, j, k) \times (l, m, n) = (a \times p, b \times q, c \times r)$$

$$P_1 \div P_2 = (i, j, k) \div (l, m, n) = (a \div p, b \div q, c \div r)$$

$$-P_1 = -(i, j, k) = (-k, -j, -i)$$

$$\mu_A(x) = \left\{ \begin{array}{ll} 0, & x \le i, \\ & . \\ \frac{x-i}{j-i}, & x \in [i, j], \\ \frac{x-k}{j-k}, & x \in [j, k], \\ 0, & x > k, \end{array} \right\} \quad (1)$$

Next, the distance between the two TFNs is calculated using Eq. (2):

$$d(P_1P_2) = \sqrt{\frac{1}{3}\left[(i - l)^2 + (j - m)^2 + (k - n)^2\right]} \quad (2)$$

3.4 Fuzzy AHP

By determining the relative importance of the system variables, the AHP technique provides analysis of the behaviour of complex systems. This aids in decision-making and the evaluation of human judgments (Vaidya and Kumar 2006; Sarminento and Thomas 2010). However, human subjectivity can only be applied within narrow limits in AHP (Chai et al. 2013). In contrast, fuzzy AHP captures human bias and lack of data clarity in decision-making

Table 3 Fuzzy linguistic scale used for determining the pairwise comparison matrix (*Source*: Wang and Chang 2007)

Linguistic variables	Fuzzy score
Approximately important	1/2, 1, 2
Approximately x times more important	x − 1, x, x + 1
Approximately x times less important	1/x + 1, 1/x, 1/x − 1
Between y and z times more important	y, (y + z)/2, z
Between y and z times less important	1/z, 2/(y + z), 1/y

The value of x ranges from 2, 3…9, whereas the values of y and z can be 1, 2……9, and y < z

and offers flexibility to managers when evaluating decision-making situations (Zyoud et al. 2016).

In the literature, fuzzy AHP has been used by researchers in different decision-making domains (e.g., Chan et al. 2008; Junior et al. 2014; Patil and Kant 2014; Prakash and Barua 2015; Adebanjo et al. 2016). As illustrated in the following stepwise procedure for this study, *fuzzy AHP* helps to determine the relative importance of listed humanitarian supply chain-related criteria and attributes involving multiple steps (Chan et al. 2008):

Step 1 Experts provide their feedback using oral/linguistic statements, and fuzzy scores are used to transform the lingual inputs into numbers. A nine-point scale of relative importance is established based on triangular fuzzy numbers (TFNs), as shown in Table 3.

Step 2 The fuzzy pairwise comparison matrices are formed through TFNs. To develop a positive fuzzy comparison matrix (M), the average of the pairwise comparisons from the expert panel is calculated. This value is given by : $M = [m_{uv}]_{n\times m}$, where m_{xy} shows the fuzzy entries in the developed fuzzy positive matrix, i.e., $\left(i_{uv}, j_{uv}, k_{uv}\right)$. Furthermore, positive fuzzy numbers should also satisfy the following properties:

$i_{uv} = \frac{1}{i_{uv}}, j_{uv} = \frac{1}{j_{uv}}, k_{uv} = \frac{1}{k_{uv}}$, where, u and v = 1, 2 …z, i.e., number of criteria

Step 3 Fuzzy numbers are aggregated into specific values to set the fuzzy or priority weights of criteria related to the problem. These weights determine the relative importance of the criteria. When it comes to priority weights of criteria, Chang's widely recognized *extent analysis* method is used to determine their relative importance (Chang 1992; Chan et al. 2008; Viswanadham and Samvedi 2013).

3.5 Fuzzy TOPSIS

Fuzzy TOPSIS (*Technique for Order of Preference by Similarity to Ideal Solution)* is a multi-criteria compromise decision technique that uses a distance measure to identify the most efficient solutions from a group of alternatives (Hwang and Yoon 1981; Chen and Hwang 1992). The most efficient solution is positioned at the minimum distance from the positive ideal solution (PIS) and the maximum distance from the negative ideal solution (NIS) (Viswanadham and Samvedi 2013; Patil and Kant 2014; Prakash and Barua 2015). The PIS minimizes the cost criteria and maximizes the benefit criteria, while the NIS achieves the opposite.

The applicability of TOPSIS has been criticized due to the presence of researcher bias (Afshar et al. 2011; Aydogan 2011). Thus, fuzzy theory can be integrated into TOPSIS, which not only helps to evaluate human inputs regarding specific values but enables criteria problems in unclear contexts to be investigated (Kuo et al. 2007; Sun 2010; Choudhary and Shankar 2012; Sindhu et al. 2017).

Fuzzy TOPSIS can be constructed along the following lines (Büyüközkan et al., 2008):

Step 1 Use fuzzy AHP to compute the priority weights of the criteria used in the study, which are represented by w_v (x = 1, 2… n).

Step 2 Decide on the linguistic expressions for the alternatives in relation to the attribute criteria, and develop the fuzzy decision matrix. Let it be assumed that there are m alternatives represented by $A=(A_1, A_2\ldots A_m)$ and that X denotes the number of probable criteria, represented by $X=(X_1, X_2\ldots X_n)$, for which the alternatives are analysed. Given Q experts, the evaluation rating of each expert, E_q (q = 1, 2… Q), for each alternative A_u in relation to each criterion C_v is illustrated by $S_q = x_{uvq}$ (u = 1,2… m; v = 1,2… n; q = 1,2… Q), membership function $\mu\tilde{S}q(x)$. For the expert rating, the linguistic scale is utilized, using Table 3. The fuzzy decision matrix for the alternatives ($\tilde{F}$)s derived using Eq. (3):

$$\tilde{F} = \begin{array}{c} A_1 \\ A_2 \\ \\ \\ A_m \end{array} \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \ldots\ldots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \ldots\ldots & \tilde{x}_{2n} \\ .. & .. & \ldots\ldots & .. \\ .. & .. & \ldots\ldots & .. \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \ldots\ldots & \tilde{x}_{mn} \end{bmatrix} \tag{3}$$

To determine the aggregate value of the fuzzy decision rating, x_{uv} for q experts, the average rating of experts needs to be computed and represented as $\tilde{x}^q_{uv} = 1/k\left(\tilde{x}^q_{uv} + \tilde{x}^q_{uv} + \tilde{x}^q_{iuvj} + \ldots \tilde{x}^q_{uv}\right)$, where $\tilde{x}^q_{ij}$ is the decision rating of alternative Ai, in relation to criterion Cj, and $\tilde{i}^q_{uv}, \tilde{j}^q_{uv}, \tilde{k}^q_{uv}$).

Step 3 Develop the normalized fuzzy decision matrix ($\tilde{R}$).. This is developed using the aggregate fuzzy decision matrix and represented as:$\tilde{R} = [r_{uv}]_{m\times n}$, where u = 1, 2… m; v = 1, 2… n. Further, r_{uv} is given by the following:

$$r_{uv} = \left(\frac{i_{uv}}{c^*_v}, \frac{j_{uv}}{c^*_v}, \frac{k_{uv}}{c^*_v}\right) \text{ and } c^*_v = \max c_{uv} \quad \text{(benefit effect)} \tag{4}$$

$$r_{uv} = \left(\frac{i^*_j}{k_{uv}}, \frac{i^*_j}{j_{uv}}, , \frac{i^*_j}{i_{uv}}, \right) \text{ and } a^*_v = \min a_{uv} \quad \text{(cost effect)} \tag{5}$$

Step 4 Develop the weighted normalized matrix: The calculated fuzzy AHP-based priority weights (w_v) of the criteria are multiplied with the normalized fuzzy decision matrix $\tilde{r}_{uv}$ to develop the weighted normalized matrix $\tilde{v}$.

$$\widetilde{V} = \left[\tilde{v}_{uv}\right]_{mxn} \quad \text{where} \quad \tilde{v}_{uv} = \widetilde{r}_{uv} \cdot w_v \tag{6}$$

Step 5 Determine the fuzzy positive ideal solution (FPIS, A^*) and fuzzy negative ideal solution (FNIS, A^-): The FPIS and FNIS are calculated using Eqs. (7, 8).

$$A^* = (\tilde{v}^*_1, \tilde{v}^*_2 \ldots \tilde{v}^*_n) \tag{7}$$

$$A^- = (\tilde{v}^-_1, \tilde{v}^-_2 \ldots \tilde{v}^-_n) \tag{8}$$

where $\tilde{v}^*_v = (0, 0, 0)$ and $\tilde{v}^-_v = (1, 1, 1)$; v = 1, 2… n.

Step 6 Determine the distance (d^+_u, d^-_u) of each weighted alternative from FPIS and FNIS (Eqs. 9, 10).

$$d_u^+ = \sum_{v=1}^{n} dv(\tilde{\vartheta}_{uv}, \tilde{\vartheta}_v^* \tag{9}$$

$$d_u^- = \sum_{v=1}^{n} dv(\tilde{\vartheta}_{uvj}, \tilde{\vartheta}_v^-) \tag{10}$$

Step 7 Determine the closeness coefficient of each alternative (D_u).

$$D_u = \frac{d_u^-}{(d_u^- + d_u^+)} \tag{11}$$

Step 8 Prioritize/rank the alternatives, taking account of the values of the closeness coefficients.

4 Proposed framework

The proposed framework for prioritizing supply partner alternatives for effective managing of *continuous-aid* procurement comprises three distinct phases, summarized in Fig. 3.

4.1 Phase 1: Identify and discern the attributes and sub-criteria relevant to partner selection

The attributes and sub-criteria for humanitarian firm partner selection are obtained from a combination of literature and expert inputs. This blend is vital because the decision domain is relatively new and it is possible that many of the relevant attributes are not defined in the literature. In these circumstances, there is a natural tendency to select attributes that are more pertinent to commercial supply chains. This tendency can be countered by incorporating feedback from experts that have many years of experience in the decision domain.

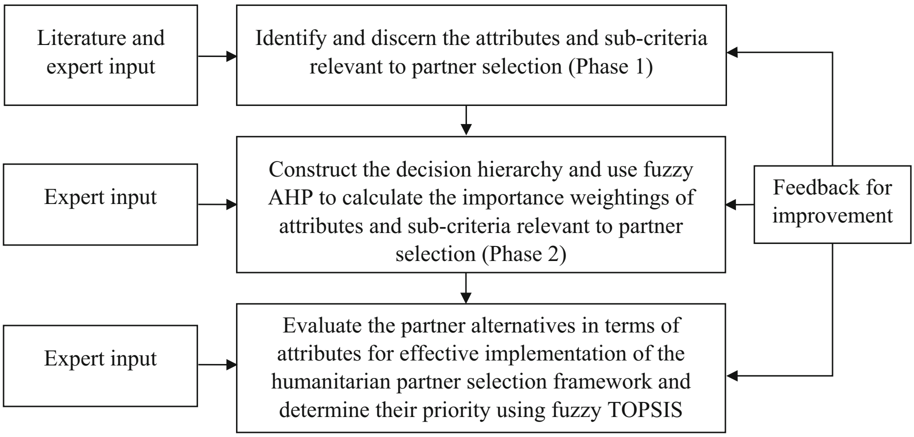

Fig. 3 Framework of humanitarian firms' supply partner selection

4.2 Phase 2: Construct the decision hierarchy and use fuzzy AHP to calculate the importance weightings of attributes and sub-criteria relevant to partner selection

A hierarchical decision structure is developed consisting of four distinct levels: investigation goal, attributes, sub-criteria, and partner alternatives. The importance weights of the attributes and criteria of the risks are calculated using fuzzy AHP. The pairwise evaluation matrix of experts' judgement is constructed, and the experts express their judgement according to the scale given in Table 3. The final pairwise evaluation matrix is then constructed and the weights of partner-related criteria calculated. The possibility of bias is handled via a moderated consensus approach.

4.3 Phase 3: Evaluate the supply partner alternatives in terms of attributes for effective implementation of the humanitarian supply programs and determine their priority using fuzzy TOPSIS

The priority or rank of the available supply partners is ordered using a fuzzy TOPSIS method. As the practical validity of solutions provided by the model will vary, the challenge is to identify close ideal solutions to the task of partner selection. These can be validated with the aid of expert feedback.

5 Case application

5.1 The case organization

The non-governmental organization 'XYZ', based in India, is used to illustrate the proposed model. XYZ was established in 1998 to deliver *'Clothing for all'*. It is a dominant player and lead organization in continuous-aid humanitarian programs throughout the Indian sub-continent. XYZ has received many international accolades for its contributions to relief efforts. It has collection centres and donors throughout the regions and supplies such relief materials as clothing. Services operate continuously throughout the year, and the demands are well monitored. XYZ's supply collection programs are triggered by information which is freely shared.

The organization has developed an extensive network that covers the 29 Indian states and has retailers, manufacturers, volunteer organizations, and educational institutions among its network partners. XYZ primarily focuses on coordinating 250 organizations, of which some 75 percent are continuous-aid partners.

XYZ uses a formal, structured exercise to assess supply partner candidates and considers sustainability to be an essential network issue. However, its partner selection procedures use attributes which are very similar to those used in a commercial environment. Hence, XYZ has a flawed evaluation scheme that cannot assess potential supply partners from a continuous-aid perspective.

5.2 Application of the humanitarian organizations supply partner selection framework

5.2.1 Phase 1: Identify and discern the attributes and sub-criteria relevant to partner selection

XYZ has five supply partner candidates from which to choose. Located in various parts of India, they all have a keen interest in collaborating with XYZ's continuous-aid humanitarian programs as part of social responsibility activity. Six attributes and (24) sub-criteria were obtained from the literature review and feedback received from eight humanitarian supply chain experts. All of the experts were selected because of their extensive pre-disaster supply chain expertise and their profile information is provided in "Appendix B".

5.2.2 Phase 2: Construct the decision hierarchy and use fuzzy AHP to calculate the importance weightings of attributes and sub-criteria relevant to partner selection

A hierarchical decision structure was constructed after finalizing the attributes, sub-criteria, and supply alternatives. This structure was fine-tuned in discussion with the six supply chain coordinators and three (different) top management executives at XYZ who manage its partner network. Final amendments, using input from the broader group of humanitarian experts, was aimed at increasing generalizability and reducing the possibility of bias.

The structure consists of four levels, illustrated in Fig. 4:

Level 1: Prioritization of the supply partners in the humanitarian organizations (the goal of the research)
Level 2: Attributes of humanitarian supply operations
Level 3: Sub-criteria of supply operations
Level 4: Supply partner alternatives

Once XYZ's supply chain executive team had approved the hierarchical decision structure, the priority weights of the attribute criteria were determined. The decision-making team provided the feedback to develop pairwise comparisons of the six attributes and 24 sub-criteria, using the scale given in Table 3. Expert opinion helped to finalize the pairwise comparison matrix of attributes and sub-criteria. Other experts outside of XYZ (Phase 1) also helped to locate significant deviations in the pairwise comparisons. This iterative process helped to build rigor into the selection process framework. Pairwise comparison of attributes is given in Table 4 (for completeness, Appendix A1 contains the triangular fuzzy number-based pairwise judgment matrices for the sub-criteria of each of the six attributes).

The pairwise comparisons were analyzed to determine the priority weights of the attributes and sub-criteria, using Chang's (1992) *extent analysis* method. The weights and rankings are shown in Table 5.

Ranking of the humanitarian supply partners was also estimated in Table 6.

5.2.3 Phase 3: Evaluate the supply 24 sub-partner alternatives in terms of attributes for effective implementation of the humanitarian supply operations and determine their priority using fuzzy TOPSIS

Based on the procedural steps described earlier for fuzzy TOPSIS, the supply chain executives at XYZ were asked to develop a fuzzy decision matrix using the linguistic scale provided in

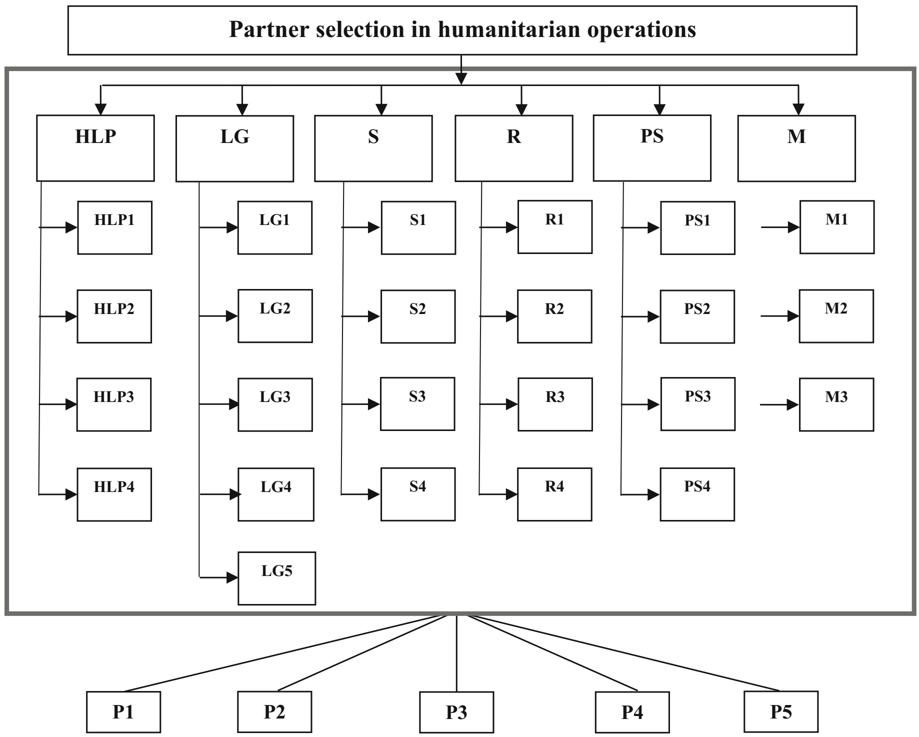

Fig. 4 Decision hierarchy for selecting a supply partner in humanitarian supply operations

Table 3. In this matrix, supply partner alternatives were compared regarding each of the identified criteria. The linguistic expressions were replaced with triangular fuzzy numbers (TFNs), and the fuzzy decision matrix of each expert developed. The resulting matrix expressed by 'Expert 1' is shown in Table 7.

The aggregate fuzzy decision matrix developed from the average of all such matrices is shown in Table 8.

The aggregate fuzzy decision matrix was transformed into a fuzzy normalized decision matrix, as shown in Table 9.

Then, the computed fuzzy AHP-based priority weights were multiplied by the fuzzy normalized decision matrix, and the fuzzy weighted matrix developed, as shown in Table 10.

A fuzzy positive ideal solution (FPIS, A^*) and a fuzzy negative ideal solution (FNIS, A^-) were given as $\tilde{v}_j^* = (0, 0, 0)$, $\tilde{v}_j^- = (1, 1, 1)$ respectively for each of these humanitarian procurement criteria. The distances $\left(d_i^+, d_i^-\right)$ of each alternative from the FPIS and FNIS were also calculated.

The distances $d(A_1, A^*)$ and $d(A_1, A^-)$ with respect to partner P1 and criteria C1 from FPIS and FNIS are shown in Table 11. Based on these distances, the closeness coefficient for partner P1 was computed.

$$D_1 = \frac{24.722}{(0.303 + 24.722)} = 0.9897$$

Table 4 Triangular fuzzy number-based pairwise judgment matrix for supply attributes

Criterion	HLP			LG			S			R			PS			M		
HLP	1.00	1.00	1.00	1.00	2.00	3.00	2.00	2.50	3.00	0.33	0.40	0.50	1.00	2.00	3.00	2.00	3.00	4.00
LG	0.33	0.50	1.00	1.00	1.00	1.00	2.00	3.00	4.00	2.00	2.50	3.00	0.33	0.40	0.50	0.33	0.50	1.00
S	0.33	0.40	0.50	0.25	0.33	0.50	1.00	1.00	1.00	0.33	0.50	1.00	2.00	3.00	4.00	3.00	3.50	4.00
R	2.00	2.50	3.03	0.33	0.40	0.50	1.00	2.00	3.03	1.00	1.00	1.00	3.00	4.00	5.00	2.00	3.00	4.00
PS	0.33	0.50	1.00	2.00	2.50	3.03	0.25	0.33	0.50	0.20	0.25	0.33	1.00	1.00	1.00	1.00	2.00	3.00
M	0.25	0.33	0.50	1.00	2.00	3.03	0.25	0.29	0.33	0.25	0.33	0.50	0.33	0.50	1.00	1.00	1.00	1.00

Table 5 Ranking of procurement attributes

Main attribute of continuous-aid procurement	Priority weight	Ranking
HLP	0.2015	2
LG	0.1962	3
S	0.1542	4
R	0.2316	1
PS	0.1163	5
M	0.1002	6

Table 6 Final ranking for criteria related to humanitarian supply partners

Main attribute	Criteria	Relative weight	Relative ranking	Global weight	Global ranking
HLP	HLP1	0.3434	1	0.0692	2
	HLP2	0.2075	4	0.0418	14
	HLP3	0.2396	2	0.0483	7
	HLP4	0.2095	3	0.0422	12
LG	LG1	0.2189	2	0.0429	11
	LG2	0.2409	1	0.0473	9
	LG3	0.1784	4	0.0350	16
	LG4	0.2144	3	0.0421	13
	LG5	0.1475	5	0.0289	21
S	S1	0.2939	2	0.0453	10
	S2	0.2251	3	0.0347	17
	S3	0.3955	1	0.0610	4
	S4	0.0855	4	0.0132	24
R	R1	0.2046	4	0.0474	8
	R2	0.2167	3	0.0502	6
	R3	0.2671	2	0.0619	3
	R4	0.3116	1	0.0722	1
PS	PS1	0.1167	4	0.0136	23
	PS2	0.4789	1	0.0557	5
	PS3	0.1339	3	0.0156	22
	PS4	0.2705	2	0.0315	20
M	M1	0.3233	2	0.0324	18
	M2	0.3579	1	0.0359	15
	M3	0.3187	3	0.0319	19

Table 7 Fuzzy decision matrix for the partner selection in humanitarian supply operations (Expert 1)

	HLP1	HLP2	HLP3	…	…	M1	M2	M3
P1	(1/2, 1, 2)	(1, 2, 3)	(1/3, 1/2, 1)	…	…	(1, 3/2, 2)	(1/2, 2/3, 1)	(1, 2, 3)
P2	(3, 7/2, 4)	(2, 5/2, 3)	(2, 3, 4)	…	…	(3, 7/2, 4)	(2, 5/2, 3)	(1/2, 1, 2)
P3	(1, 2, 3)	(1/2, 1, 2)	(1/2, 2/3, 1)	…	…	(2, 5/2, 3)	(1/2, 1, 2)	(1, 2, 3)
P4	(1, 2, 3)	(1, 2, 3)	(1/2, 1, 2)	…	…	(2, 3, 4)	(2, 5/2, 3)	(2, 3, 4)
P5	(1/2, 1, 2)	(1, 2, 3)	(2, 3, 4)	…	…	(2, 3, 4)	(3, 4, 5)	(4, 5, 6)

In this manner, distances $d(A_1, A^*)$ and $d(A_1, A^-)$ were calculated for each partner, and the corresponding closeness coefficients were computed.

6 Sensitivity analysis

Sensitivity analysis was used to test the robustness of the framework (Patil and Kant 2014). A discussion with the experts helped to manage possible conflicts when six proposed sensitivity analysis cases were being considered. The use of fuzzy concepts was very helpful at this point for handling expert bias and lack of clarity. Using TFNs allowed the experts to express their opinions as interval values rather than crisp values, which may be biased or which lack clarity most times. The experts concurred on the choice of six cases, the details of which are summarized in Table 12. For the first five experiments (Exp 1–5), the priority weight of a single criterion was set higher than the others, which were set to the same low value of importance. For example, in Exp 1, the weight of the HLP1 criterion was set to 0.6, and the weights of the remaining 23 criteria were assigned a weight of 0.01,739. For Exp 6, all of the criteria were considered to be equally important and assigned the same weight (0.0416).

It was observed that the scores of the closeness coefficient, and hence the final ranking of the supply partners, changed with the criterion weights. Figure 5 reveals that candidate supply partner S5 registered the maximum closeness coefficient value in three out of the six experiments (experiments 3, 4, and 6). For the other three experiments, partner S3 obtained the maximum score and was ranked first among the partners. The final rank of the remaining partners also changed. For this case at least, it appears that the final rank of the candidate supply partners for managing the *continuous-aid* humanitarian chain procurement program is reasonably sensitive to criterion weighting values.

7 Discussion and managerial implications

The proposed framework was designed for NGOs involved in continuous-aid collection activities, to help them select suitable supply partners. Application of the fuzzy *AHP and TOPSIS* technique to a leading Indian humanitarian aid organization has significantly streamlined their selection process.

The study establishes that responsiveness (R) is the most preferred attribute, and the experts explained how partners are expected to have excellent control of procurement lead-times and strong network management skills supported by transparent information systems. Our results also corroborate the arguments of Taupiac (2001) that the fast delivery of relief materials is a characteristic of a continuous-aid system (like tents and medical aids), though some of them

Table 8 Aggregate fuzzy decision matrix for the partner selection in humanitarian supply operations

	HLP1	HLP2	HLP3	…	…	M1	M2	M3
P1	0.7, 1.2, 2	2, 3.1, 3.4	0.5, 0.5, 1.2	…	…	2, 1.78, 2	0.5, 0.66, 0.9	0.89, 1.9, 3
P2	2.78, 3.5, 3.91	1.2, 1.45, 2.1	1.9, 1.2, 3.82	…	…	3.1, 3.5, 4.2	2.1, 2.71, 3.5	0.5, 1.1, 2
P3	1.1, 2, 3.2	3.1, 1.9, 1.2	0.45, 0.67, 1.64	…	…	2.12, 2.5, 3.56	0.5, 1.1, 2.89	1.1, 2, 3.5
P4	0.92, 2.1, 3.2	1.45, 2.21, 1.5	0.6, 0.4, 1.95	…	…	1.9, 3, 4.4	2, 2.7, 3.23	1.9, 3, 4.50
P5	0.45, 0.9, 2.12	1.12, 1.93, 3.1	2.1, 3.41, 4.3	…	…	2.2, 3.2, 2.4	2.8, 4.3, 5.5	2.1, 2.4, 3.1

Table 9 Normalized fuzzy decision matrix for the partner selection

	HLP1	HLP2	HLP3	…	…	M1	M2	M3
P1	0.165, 0.275, 0.471	0.097, 0.106, 0.165	0.275, 0.66, 0.66	…	…	0.165, 0.185, 0.165	0.366, 0.5, 0.66	0.11, 0.173, 0.370
P2	0.109, 0.122, 0.154	0.204, 0.296, 0.358	0.112, 0.358, 0.226	…	…	0.102, 0.122, 0.138	0.122, 0.158, 0.204	0.215, 0.390,0.86
P3	0.078, 0.125, 0.227	0.208, 0.131, 0.080	0.156, 0.373,0.555	…	…	0.070, 0.1,0.117	0.086, 0.227, 0.5	0.071, 0.125, 0.227
P4	0.156, 0.238, 0.543	0.333, 0.226, 0.344	0.256, 1.25, 0.833	…	…	0.113, 0.166, 0.263	0.154, 0.185, 0.25	0.111, 0.166, 0.263
P5	0.193, 0.455, 0.911	0.132, 0.212, 0.366	0.095, 0.120, 0.195	…	…	0.170, 0.128, 0.186	0.074, 0.095, 0.146	0.132, 0.170, 0.195

Table 10 Weighted normalized fuzzy decision matrix for the partner selection

	HLP1	HLP2	HLP3	…	…	M1	M2	M3
P1	0.011, 0.019, 0.032	0.004, 0.004, 0.006	0.013, 0.031, 0.031	…	…	0.005, 0.006, 0.005	0.013, 0.017, 0.023	0.003, 0.005, 0.011
P2	0.007, 0.008, 0.010	0.008, 0.012, 0.014	0.005, 0.017, 0.010	…	…	0.003, 0.003, 0.004	0.004, 0.005, 0.007	0.006, 0.012, 0.027
P3	0.005, 0.008, 0.015	0.008, 0.005, 0.003	0.007, 0.018, 0.026	…	…	0.002, 0.003, 0.003	0.003, 0.008, 0.017	0.002, 0.003, 0.007
P4	0.010, 0.016, 0.037	0.013, 0.009, 0.014	0.012, 0.060, 0.040	…	…	0.003, 0.005, 0.008	0.005, 0.006, 0.008	0.003, 0.005, 0.008
P5	0.013, 0.031, 0.063	0.005, 0.008, 0.015	0.004, 0.005, 0.009	…	…	0.005, 0.004, 0.006	0.002, 0.003, 0.005	0.004, 0.005, 0.006

Table 11 Summary of closeness coefficients (D_u) and the final partner ranking

Partner available for selection	d_u^-	d_u^+	D_u	Ranking
P1	0.303	24.722	0.9879	3
P2	0.384	24.655	0.9847	5
P3	0.252	24.777	0.9899	2
P4	0.313	24.717	0.9875	4
P5	0.250	24.770	0.9900	1

Table 12 Results of sensitivity analysis test

Description of the experiment	S1	S2	S3	S4	S5
Actual weights used	0.9879	0.9847	0.9899	0.9875	0.9900
Exp 1: 1st = 0.6, Remainder = 0.01739	0.9425	0.9349	**0.9550**	0.9408	0.9489
Exp 2: 2nd = 0.6, Remainder = 0.01739	0.9918	0.9868	**0.9923**	0.9876	0.9899
Exp 3: 3rd = 0.6, Remainder = 0.01739	0.9817	0.9903	0.9881	0.9832	**0.9930**
Exp 4: 4th = 0.6, Remainder = 0.01739	0.9920	0.9878	0.9885	0.9860	**0.9931**
Exp 5: 5th = 0.6, Remainder = 0.01739	0.9870	0.9752	**0.9927**	0.9903	0.9921
Exp 6: All = 0.0416	0.9875	0.9848	0.9898	0.9872	**0.9901**

may be very simple items for logistics. Moreover, other operational parameters (M) such as service portfolio and flexibility have found a due place in the proposed scheme as advocated by Oloruntoba and Gray (2006), but interestingly, they are less prioritized compared to other study attributes of continuous-aid environment.

This study directly supports the extant literature that large inventory pre-positioning is riskier and leads to underutilization of the assets (Beamon and Kotleba 2006). Hence, humanitarian firms largely depend on partners' responsiveness for their effective performance. On the other side, this triggers those firms to have proactive and appropriate inventory strategies at different nodes combined with the effective supplier coordination to prevent the loss of life (Beamon and Kotleba 2006; Falasca and Zobel 2011). Our findings also emphasize aligning responsiveness to effectively manage partner (supplier) capacity, inventory buffers at the humanitarian organization, acquisition costs, and the overall demand, including perishable materials in the procurement system (Balcik and Beamon 2008). Nevertheless, this strategy may lead to some complexities in the supply process, as not all organizations (supply or partner) can maintain a network of warehouses and align towards the specific distribution patterns of humanitarian firms. Many reasons, including their firm size and transaction volume in the humanitarian operations, can be attributed to that. In any case, the humanitarian organizations expect to have a specific individual strategy for in-kind donations and procured supplies. Thus, we suggest that the periodic announcement of donations, seasonal procurement initiatives, and special collection drives, such as combined programs with other

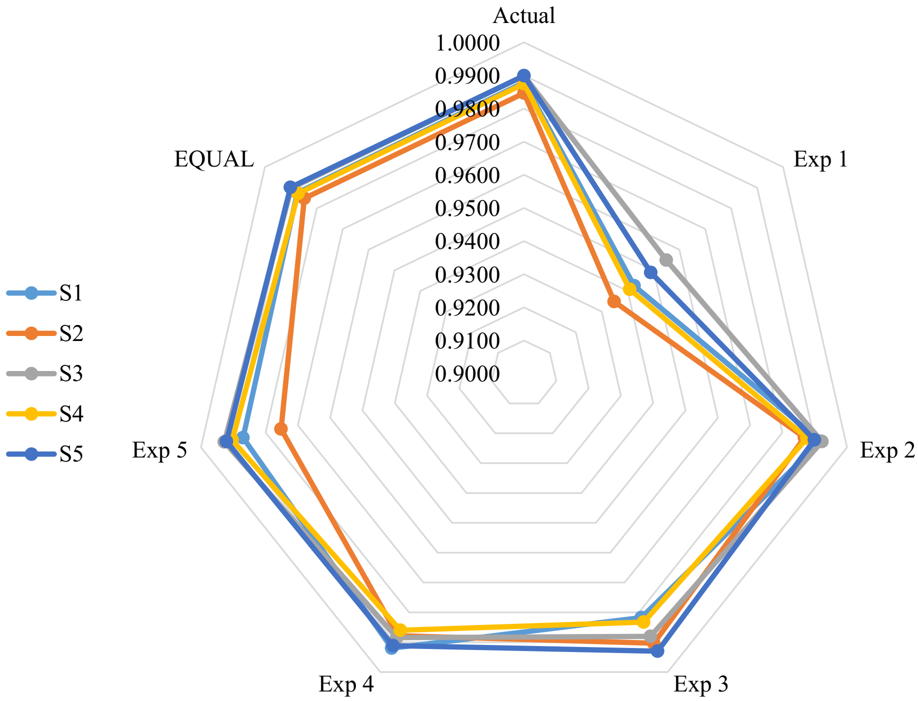

Fig. 5 Closeness coefficient scores obtained through sensitivity analysis

agencies, need to have a synergy with the overall humanitarian firm's operational objectives. Such planned real-time replenishment initiatives can effectively handle the responsiveness of the supplier firms and significantly reduce the overall transportation cost by re-engineering the procurement schemes (Chakravarty 2014).

Partner selection in the continuous-aid humanitarian operations setting is a strategic issue in the procurement domain, and the proposed framework has significant implications for humanitarian operations. Firstly, it will help humanitarian relief procurement managers to select and prioritize supplier selection attributes which can be different to those of commercial organizations. It will help to design a specific supplier selection framework for the continuous-aid environment, which is different to disaster-triggered relief chains. Secondly, it can help operations executives to avoid bias and partiality by allowing consideration of the many attributes they deem essential for successful humanitarian chain procurement operations. For example, the focal organization might choose to enter into a partner selection process that considers logistics performance, legal implications, partnership strategy and other operational factors in addition to supplier responsiveness. Thirdly, this selection methodology would help the humanitarian organization to effectively plan their overall procurement and replenishment strategy by studying or giving due weights to the respective attributes. However, it is recognized that the priority weightings used may differ between diverse cultural settings and types of procurement programs, and they may also vary depending on the nature of the supply materials and partner locations, among other factors. This may trigger a supply chain coordination through effective auditing and training of the continuous-aid partners.

8 Conclusion, limitations, and future scope of research

Relief material supplies acquisition and logistics are crucial in humanitarian operations. Much attention is given in practice, as well as in the literature, to pre-positioning and inventory management of relief materials, but only recently have researchers begun to realize the importance of supplies acquisition. Relief materials acquisition for *continuous-aid* humanitarian supply chain operations involves distinctively different considerations to similar commercial and *disaster-triggered* procurement activities. Relief organizations often work with just a few partners over the long term, making a robust supply partner selection strategy a strategic imperative for successful *continuous-aid* humanitarian operations. Surprisingly, to the best of our knowledge, no research has investigated this issue.

This paper makes several significant contributions. First, it is pioneering work on the partner selection problem in the context of *continuous-aid* humanitarian supply chain operations. The problem is significant and warrants further study. Second, it identifies critical criteria for partnership selection in *continuous-aid* relief operations. These comprise six attributes and 24 sub-criteria based on data from experienced relief workers. As the first set of criteria identified for *continuous-aid* relief operations in the literature, this study will serve as an essential reference for future studies. Third, a *fuzzy AHP-TOPSIS* analytical framework is developed for solving the partner selection problem. The method is innovative and rigorous and suits decisions that involve human judgments which are inherently imprecise and vague. A numerical case study demonstrates the applicability of this *fuzzy AHP-TOPSIS* analytical framework. The case results suggest that the weights assigned to criteria can have a considerable effect on the partner selection decision. Overall, application of *Fuzzy TOPSIS* made partner selection easier to handle compared to using *AHP* or *fuzzy AHP* alone. The findings demonstrate the value of arriving at the final selection by incorporating feedback from multiple experts who have different background in humanitarian operations, instead of focusing only on the procurement leaders' input.

This research has its limitations and therefore offers some future study directions. First, it does not distinguish the different systems of continous-aid procurement process such as in-kind donations and procured supplies. The present ranking and overall supplier selection scheme may vary in those specific settings. Thus, future comparative studies focusing on those procurement patterns are recommended to draw more insights on the behaviors of humanitarian organizations. Second, the experts who were involved during the different phases may have expressed opinions that are biased by their experiences in other associated domains of humanitarian logistics, such as warehouse management, relief-fund management, liaising with government authorities, and so on. As the practical validity of solutions provided by the model may vary, the challenge is to identify close to ideal solutions to the task of partner selection. For further validity, studies involving only the relief procurement experts of well-established global level continous-aid humanitarian organizations (such as *Red Cross* and *UN relief institutions*) are recommended. Third, since continous-aid (development-aid) procurement is an emerging domain compared to disaster relief operations procurement, which itself has only a limited literature, the results may need to be verified through large scale empirical studies. In addition, studies on procurement behaviours involving collection patterns and supply partner psychology are also recommended. Fourth, while the *fuzzy AHP-TOPSIS* analytical framework developed in this paper has proven to be useful for solving the partner selection problem, it would be interesting to apply other multi-criteria decision methods to solve the same problem and compare their respective advantages and disadvantages. Finally, the criteria used for partner selection in *continuous-aid relief* operations were based on circumstances that exist in India's national setting. Future studies might usefully collect data from different national settings for comparative analysis.

Appendix A

See Tables 13, 14, 15, 16, 17 and 18.

Table 13 Triangular fuzzy number-based pairwise judgment matrix for sub-criteria—HLP

	HLP1			HLP2			HLP3			HLP4		
HLP1	1.00	1.00	1.00	3.00	4.00	5.00	2.00	2.50	3.00	0.50	1.00	0.50
HLP2	0.20	0.25	0.33	1.00	1.00	1.00	0.25	0.33	0.50	1.00	2.00	3.00
HLP3	0.33	0.40	0.50	2.00	3.03	4.00	1.00	1.00	1.00	0.33	0.50	1.00
HLP4	2.00	1.00	2.00	0.33	0.50	1.00	1.00	2.00	3.03	1.00	1.00	1.00

Table 14 Triangular fuzzy number-based pairwise judgment matrix for sub-criteria—LG

	LG1			LG2			LG3			LG4			LG5		
LG1	1.00	1.00	1.00	0.33	0.50	1.00	2.00	2.50	3.00	0.33	0.50	1.00	2.00	3.00	4.00
LG2	1.00	2.00	3.03	1.00	1.00	1.00	2.00	3.00	4.00	2.00	2.50	3.00	0.33	0.40	0.50
LG3	0.33	0.40	0.50	0.25	0.33	0.50	1.00	1.00	1.00	0.33	0.50	1.00	2.00	3.00	4.00
LG4	1.00	2.00	3.03	0.33	0.40	0.50	1.00	2.00	3.03	1.00	1.00	1.00	1.00	2.00	3.00
LG5	0.25	0.33	0.50	2.00	2.50	3.03	0.25	0.33	0.50	0.33	0.50	1.00	1.00	1.00	1.00

Table 15 Triangular fuzzy number-based pairwise judgment matrix for sub-criteria—S

	S1			S2			S3			S4		
S1	1.00	1.00	1.00	2.00	3.00	4.00	0.25	0.33	0.50	1.00	2.00	3.00
S2	0.25	0.33	0.50	1.00	1.00	1.00	0.25	0.33	0.50	1.00	2.00	3.00
S3	2.00	3.03	4.00	2.00	3.03	4.00	1.00	1.00	1.00	2.00	3.50	4.00
S4	0.33	0.50	1.00	0.33	0.50	1.00	0.25	0.29	0.50	1.00	1.00	1.00

Table 16 Triangular fuzzy number-based pairwise judgment matrix for sub-criteria—R

	R1			R2			R3			R4		
R1	1.00	1.00	1.00	2.00	3.00	4.00	0.25	0.33	0.50	0.25	0.33	0.50
R2	0.25	0.33	0.50	1.00	1.00	1.00	2.00	3.00	4.00	0.33	0.28	0.25
R3	2.00	3.03	4.00	0.25	0.33	0.50	1.00	1.00	1.00	1.00	2.00	3.00
R4	2.00	3.03	4.00	4.00	3.57	3.03	0.33	0.50	1.00	1.00	1.00	1.00

Table 17 Triangular fuzzy number-based pairwise judgment matrix for sub-criteria—PS

	PS1			PS2			PS3			PS4		
PS1	1.00	1.00	1.00	0.25	0.33	0.50	1.00	2.00	0.50	0.50	1.00	0.50
PS2	2.00	3.03	4.00	1.00	1.00	1.00	2.00	3.00	4.00	2.00	2.50	3.00
PS3	2.00	0.50	1.00	0.25	0.33	0.50	1.00	1.00	1.00	0.25	0.33	0.50
PS4	2.00	1.00	2.00	0.33	0.40	0.50	2.00	3.03	4.00	1.00	1.00	1.00

Table 18 Triangular fuzzy number-based pairwise judgment matrix for sub-criteria—M

	M1			M2			M3		
M1	1.00	1.00	1.00	1.00	2.00	3.00	0.33	0.50	1.00
M2	0.33	0.50	1.00	1.00	1.00	1.00	2.00	3.00	4.00
M3	1.00	2.00	3.03	0.25	0.33	0.50	1.00	1.00	1.00

Appendix B

See Table 19.

Table 19 Participant profile

No.	Profile	Expertise in humanitarian operations domain	Experience
1.	Operations/administration Head	Strategy and operations	More than 22 years
2.	Senior supply chain coordinator	Government liasoning and supply chain planning and stakeholder relationships	More than 13 years
3.	Collections in-charge	Procurement and Supplier relationships	More than 15 years
4.	Regional coordinator—South	Stakeholder relationships/planning	More than 20 years
5.	Warehouse manager	Inventory, procurement coordination, and distribution	More than 25 years
6.	Distribution/Logistics manager	Dispatch coordination and planning in Humanitarian operations	More than 10 years
7.	Senior development (Aid) monitoring expert	Monitoring the implementation of sponsored projects with the development aid from different partners including government	More than 15 years
8.	Supply chain executive	Stakeholder interaction/Supplier coordination	More than 10 years

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