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## Abstract

**Purpose** – The purpose of this paper is to explore the barriers to coordination in humanitarian supply chain management (HSCM), proposes solutions and prioritizes them to overcome the barriers particularly in the Indian context.

**Design/methodology/approach** – This study adopts a comprehensive and rigorous procedure to explore the barriers and solutions to coordination in HSCM. The research design is divided into three phases; first, the barriers and solutions are collected through an extensive literature review; second, barriers and solutions were verified with experts involved in relief operations of the disaster that occurred in Uttarakhand (a Northern state in India) on June 14, 2013 and finally, based on the weight of barriers estimated by fuzzy analytic hierarchy process, solutions to overcome the barriers are prioritized using fuzzy technique for order performance by similarity to ideal solution that considers uncertainty and impreciseness rather than a crisp value.

**Findings** – This study explored 23 barriers to coordination in HSCM and grouped into five categories i.e., strategic barriers, individual barriers, organizational barriers, technological barriers and cultural barriers, and finally 15 solutions were proposed and prioritized to overcome the barriers so decision makers can focus on overcoming these barriers and realize the benefits of coordination in HSCM.

**Practical implications** – This study provides a more efficient, effective, robust and systematic way to overcome barriers to coordination and improve the competencies of humanitarian supply chain (HSC).

**Originality/value** – This is the first kind of study that prioritizes the solutions to enhance coordination in HSC based on the weight of the barriers.

**Keywords** Analytical hierarchy process, Barriers, Coordination, Drivers, Fuzzy TOPSIS, Supply chain management

**Paper type** Research paper

## 1. Introduction

During the past decades, humanitarian supply chain (HSC) has received greater attention among the academicians and practitioners (Kovacs and Spens, 2010). Coordination among actors involved in the relief operations is gaining momentum in India, due to the rise in the occurrence of disasters as India is prone to natural disasters (USAID, India, 2006) and is one of the most disasters prone country in the world due to its unique geo-climatic condition. Floods, earthquakes, cyclones, droughts and

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landslides are common in India (Ministry of Home Affairs India, 2011). India has witnessed devastating natural disasters in the recent past like super cyclones in Orissa in the year 1999, an earthquake in the Gujarat in the year 2001, Tsunami in the coastal states in 2004; recently (June 2013) disaster in Uttarakhand.

Disasters not only disturb the normal functioning of the society, but also leaves a lasting impact on the people who are directly or indirectly related to it (Alexander, 1997). It is not possible to predict natural disasters but actions can be taken to deal with a complex crisis to reduce the impact of the disaster on people and society (Kovacs and Spens, 2007; Centre for Science and Environment, 1996).

Actors involved in relief activities should work in a coordinated manner since a single organization is less effective in responding to the needs and wants of people affected by disasters even though they may be well prepared to respond to a disaster (Van Wassenhove, 2006; Akhtar *et al.*, 2012; Bremer, 2003). During the relief activities in Uttarakhand, the lack of coordination hampered the relief and rescue operations (*Times of India*, 2013). Better coordination between the relief actors, would have reduced the impact of this calamity. Coordination between the actors involved in relief activities provides an opportunity to analyze the situation more clearly and can help articulate a better strategy for the welfare of disaster victims in the short term (Cozzolino, 2012; Schulz, 2009; Kovacs and Spens, 2009; Datta and Christopher, 2011). For example, joint plans can maximize the use of limited resources and coordinated resource procurement can lower costs that could ultimately reduce the level of competition and improve service to aid recipients (Balcik *et al.*, 2010; Moore *et al.*, 2003; Kehler, 2004). Pasupuleti (2013) also demonstrated the importance of "connectivity" as a construct of cultural continuity that links approaches for designing culturally responsive built environments in post disaster reconstruction process.

Samii and Van Wassenhove (2003) reported the importance of increased levels of coordination between different humanitarian relief organizations, but the literature on disaster management provides several examples of the scarcity of coordination in relief activities, for e.g. 2004 Indian Ocean Tsunami by Van Wassenhove (2006), 2005 hurricane Katrina by Cordoba (2010) and for the 2010 Haiti earthquake by Farazmand (2007). Numerous impacts were seen in past relief activities due to lack of coordination such as ineffective last mile aid distribution (Murray, 2005); competition among actors for scarce resources (Steinberg, 2007); congestion at airports and local roads that raises costs and delay services (Fritz Institute, 2005). All of this contributes to the injury or death of aid recipients struggling to attain medical services (Chang *et al.*, 2010; Moore *et al.*, 2003). Thévenaz and Resodihardjo (2010) observed that due to ineffective coordination "efforts are duplicated, resources are used in an unproductive and ineffective way or are wasted, and relief efforts are slow, impeded, or obstructed."

In spite of benefits, coordination is found to be the most important problem among the stakeholders, from both the government and the private sector in HSC (Fritz Institute, 2005; McLachlin and Larson, 2011; Sandwell, 2011; Whiting and Ayala-Ostrom, 2009). In addition, the work carried out by some of the contemporary researchers like Kovacs and Spens (2007), Apte (2010), Van Wassenhove (2006) and Balcik *et al.* (2010) have helped to underpin the following research gaps (RG) in Indian context:

*RG1*. Lack of studies highlighting the barriers to coordination and solutions to enhance the coordination in HSC.

*RG2*. Lack of studies prioritizing the solutions to enhance coordination on the basis of weight of the barriers.

Therefore, this study examined 23 barriers and explored 15 solutions with the help of a literature review and brainstorming sessions with experts. The details of the experts are given in Table I. Fuzzy analytic hierarchy process (AHP) was used to estimate the weight of barriers while fuzzy technique for order performance by similarity to ideal solution (TOPSIS) helped to prioritize the solutions that enhance the coordination between actors involved in relief activities. This framework provides a more precise, efficient, effective, robust and a systematic decision support tool for a stepwise implementation of solutions to enhance coordination between actors involved in HSC.

The rest of the paper is organized as follows: Section 2 lists the barriers to coordination and solutions to overcome the barriers. The methodology adopted for the study is explained in the Section 3. Section 4 explains the application of the proposed framework. Section 5 presents the findings and discussion of the study. Section 6 presents the contributions of the study and finally in the Section 7, limitations of the study and the paper related future work is presented.

## 2. Literature review

The management of humanitarian relief activities is complex due to a large number of stakeholders from both the government and private sector (Balcik *et al.*, 2010; Dolinskaya *et al.*, 2011). Moreover, challenges arise due to a lack of policies and financial incentives regarding coordination (Tomasini and Van Wassenhove, 2009; McLachlin and Larson, 2011). According to Balcik *et al.* (2010), the factors that affect the coordination of HSC are the "number of diverse actors, donor expectations and funding structures, competition for funding, uncertainty about the occurrence of a disaster, resource scarcity and oversupply."

Fritz Institute (2005) reported that some of the problems while delivering aid include the shortage of expert logisticians, limited collaboration and coordination, manual supply chain processes, and inadequate assessments and planning. Many researchers have confirmed the shortage of experienced logisticians since it is not considered a professional discipline (Gustavsson, 2003; Maiers *et al.*, 2005, Balcik *et al.*, 2010; Whiting and Ayala-Ostrom, 2009).

The utilization of IT is low in HSC as compared to commercial supply chain (CSC) and the key problem emphasized by practitioners to enhance the technical capabilities of the humanitarian sector is the behavior of donors (Thomas, 2003; Gustavsson, 2003). Murray (2005) and Whiting and Ayala-Ostrom (2009) also emphasized that the behavior of donors reflect that their money should be used to help disaster victims after the occurrence of an event, which means avoidance techniques are often ignored, particularly by developing countries (Kovacs and Spens, 2007).

| Designation | Years of experience | Qualification | Gender |
|---|---|---|---|
| Logistics Officer | 10 | Post-graduate | M |
| Medical Logistician | 10 | MBBS, MD | M |
| Senior Operation Officer | 12 | BE, PhD | M |
| Assistant Director | 15 | Post-graduate | F |
| Director | 20 | BE, ME, PhD | F |
| Professor | 25 | Btech, Mtech, PhD | M |
| Logistics Officer | 10 | Post-graduate | M |
| Managing Director | 20 | Graduate | F |

**Table I.** Profile of experts

Many researchers have highlighted the importance of coordination between actors in relief activities and reported that this area requires major attention (McClintock, 2005; Sowinski, 2003; Murray, 2005). Despite this, Davidson (2006) reported that the biggest challenge is the existing culture within the HSC; the way performance is monitored and analyzed is inefficient. The barriers to coordination in HSC are listed in Table II.

### *2.1 Solutions to enhance coordination in humanitarian supply chain management (HSCM)*

Van Brabant (1999) reported that "similar standards of quality, cost-effective use of resources, rational allocation of tasks, and working towards agreed priorities" promote coordination among humanitarian actors. Researchers have suggested varied and situation specific solutions to overcome the challenges to enhance coordination in HSCM (Table III) in order to improve the efficiency of relief operations (WHO, 2007, New Delhi, India). A strategic tie up between actors involved in relief activities can have a positive influence on the performance and knowledge sharing capabilities of organizations (McEntire, 2002).

Top management commitment and an effective performance management system are vital in order to overcome the problem of funds, strategic planning, awareness, trust and other issues (Thevenaz and Resodihardjo, 2010; Waugh and Streib, 2006; Smith and Dowell, 2000; Ponomarov and Holcomb, 2009; Agostinho, 2013; Moshtari and Gonçalves, 2011; Gunasekaran *et al.*, 2004). The mutual learning of commercial and humanitarian organizations is crucial to enhance the competence of supply chain (SC) partners (Agostinho, 2013). Joerin *et al.* (2012) reported that community-driven participatory solutions in collaboration with other stakeholders have beneficial effect in enhancing the resilience of communities to climate-related disasters.

Regular meetings between actors are essential to evaluate the effectiveness of current relief activities (McEntire, 2002). The use of IT enhances the agility and flexibility in supply chain (Gunasekaran and Ngai, 2004). Advanced IT systems that can be used to store, retrieve and share information across organizational boundaries (McEntire, 2002; Balcik *et al.*, 2010; Schulz and Blecken, 2010; Agostinho, 2013; Maiers *et al.*, 2005; Dejohn, 2005; Gunasekaran *et al.*, 2006; Mandal and Gunasekaran, 2003) are of utmost need (Lee and Zbinden, 2003; Kala, 2014). Establishing a transparent work flow policy in an organization supports the flow of information at different levels within the HSC and ensures flexibility, agility and alignment in a command chain (Sheffi and Rice, 2005). Strengthening cultural cohesion and cooperation among the actors will help bridge the cultural gap between different actors (Balcik *et al.*, 2010; Sheffi and Rice, 2005; Agostinho, 2013). Web based systems for easy access and easy to use information sharing and communication tools are required to promote information sharing (Balcik *et al.*, 2010; Schulz and Blecken, 2010). Raju and Becker (2013) reported the factors that affect coordination in long-term recovery process are "the need to coordinate, the role of the government, knowledge networking, mandates and goals and coordination at the donor level."

The financial supply chain needs to be accountable and transparent so donors can see how the money they donated is utilized (Balcik *et al.*, 2010; Agostinho, 2013; Thomas and Kopczak, 2005). It is essential to view the process of disaster management holistically instead of a short-term view (Schulz and Blecken, 2010; Kovacs and Spens, 2007; Natarajarathinam *et al.*, 2009; Pettit and Beresford, 2005; Agostinho, 2013; Moshtari and Gonçalves, 2011; Maiers *et al.*, 2005) and a feedback mechanism is

| Main criteria | Code | Sub–criteria | References |
|---|---|---|---|
| Strategic barriers | SB1 | Lack of top management commitment toward enhancing coordination | Lester and Krejci (2007), Moshtari and Gonçalves (2011) |
| | SB2 | Lack of supply chain understanding | Agostinho (2013) |
| | SB3 | Lack of collaborative and strategic planning or short-term oriented planning | McConnell (2003), Boin (2005), Moshtari and Gonçalves (2011), Maiers *et al.* (2005) |
| | SB4 | Lack of clear policies for coordination | Byman *et al.* (2000) |
| | SB5 | Shortage of experts logisticians | Gustavsson (2003), Maiers *et al.* (2005) |
| | SB6 | Lack of human resource for coordination | Balcik *et al.* (2010) |
| Technological barriers | TB1 | Lack of funds for investment in IT | Balcik *et al.* (2010), Maiers *et al.* (2005) |
| | TB2 | Poor IT infrastructure | Schulz and Blecken (2010), Agostinho (2013), Maiers *et al.* (2005), Kabra and Ramesh (2013a, b, c) |
| | TB3 | Manual supply chain | Maiers *et al.* (2005) |
| | TB4 | Disparity in IT facility among actors involved | Schulz and Blecken (2010), Maiers *et al.* (2005) |
| | TB5 | Lack of technical assistance to SC members | Agostinho (2013), Maiers *et al.* (2005) |
| Cultural barriers | CB1 | Cultural difference among actors | Balcik *et al.* (2010), McEntire (2002), Thomas and Kopczak (2005) |
| | CB2 | Lack of willingness and information sharing spirit among actors | Balcik *et al.* (2010), McEntire (2002) |
| | CB3 | Lack of trust among actors | Balcik *et al.* (2010), McEntire (2002), Moshtari and Gonçalves (2011) |
| Individual barriers | IB1 | Lack of time to share knowledge | Balcik *et al.* (2010) |
| | IB2 | Lack of education and training to SC members | Thevenaz and Resodihardjo (2010), Agostinho (2013), Maiers *et al.* (2005) |
| | IB3 | Poor verbal/written communication, interpersonal and computer skills | Overstreet *et al.* (2011) |
| | IB4 | Resistance to change and adopt new skills | Maiers *et al.* (2005) |
| | IB5 | Lack of motivation | Moshtari and Gonçalves (2011), Tchouakeu *et al.* (2011) |
| Organizational barriers | OB1 | Lack of proper organizational structure to create and share knowledge | McEntire (2002); Schulz and Blecken (2010), Maiers *et al.* (2005) |
| | OB2 | Retention of highly skilled and experienced staff is not a high priority | Maiers *et al.* (2005) |
| | OB3 | Lack of knowledge management system | Balcik *et al.* (2010), McEntire (2002), Agostinho (2013), Maiers *et al.* (2005) |
| | OB4 | Lack of accountability and transparency for donors | Agostinho (2013), Thomas and Kopczak (2005) |

**Table II.** Contemporary literature on barriers of coordination in HSC

| Sl. No | Solutions | Definition | Reference |
|---|---|---|---|
| S1 | Strategic tie up between actors | Strategic tie-ups refer to the joint work of two or more organizations for the betterment of relief activities not only during a disaster but also before a disaster | McEntire (2002) |
| S2 | Commitment from the actors involved in HSC | Commitment means the intention to advocate and support the process at every stage | McEntire (2002), Schneider (1995), Tierney (1985), Thevenaz and Resodihardjo (2010), Christopher and Peck (2004) |
| S3 | Use of information technology | IT systems can be used to store, retrieve and share information for processing across organizational boundaries | McEntire (2002), Balcik *et al.* (2010), Schulz and Blecken (2010), Agostinho (2013), Maiers *et al.* (2005), Dejohn (2005) |
| S4 | Regular meetings between actors of HSC | In order to analyze the strengths and weaknesses of any relief operations and to further improve the efficiency, the actors should meet regularly and not only at the time of a disaster | McEntire (2002), Kabra and Ramesh (2013a) |
| S5 | Build trustworthy environment within SC members | A trustworthy environment refers to an environment that supports information sharing, which is essential for motivating the actors toward a higher level of coordination | McEntire (2002), Sheffi and Rice (2005), Moshtari and Gonçalves (2011), Maiers *et al.* (2005) |
| S6 | Mutual learning of commercial and humanitarian organizations | Mutual learning means policy makers and supply chain experts exchange knowledge on issues of common concern in order to improve coordination and decision making | Agostinho (2013), John and Ramesh (2012) |
| S7 | Strengthen the cultural cohesions and cooperation's among the actors | Improving cultural cohesion facilitates the development of employees at every level regarding what the supply chain needs from them as an individual or as a part of team and supports information sharing | Balcik *et al.* (2010), Sheffi and Rice (2005), Agostinho (2013) |
| S8 | Well planned, efficient and effective training of workers | Disaster management training refers to educating workers about emergencies, needs assessment, and which information needs to be transferred to get the right | McEntire (2002), Drabek (1985), Thevenaz and Resodihardjo (2010), Agostinho (2013), Maiers *et al.* (2005), Thomas and Mizushima (2005) |

**Table III.**
Solutions to overcome barriers to coordination in HSC

(*continued*)

| Sl. No | Solutions | Definition | Reference |
|---|---|---|---|
| | | kind of help. Training is critical for capacity building so trained personnel can respond more effectively and efficiently to different kinds of disasters | |
| S9 | Establish a transparent work flow or open door policy | A transparent work flow encourages information sharing among actors at all levels of supply chain and ensures agility, adaptability and alignment in the chain | Sheffi and Rice (2005), Patil and Kant (2014) |
| S10 | Evaluation on the effectiveness and efficiency of performance measurement system (PMS) at place | PMS are systems that enable an organization to enhance their efficiency and effectiveness by improving the decision-making process. Measuring the performance of relief operations is very difficult, hence the importance of an efficient PMS | Balcik *et al.* (2010), Thomas and Kopczak (2005), Agostinho (2013) |
| S11 | Web based systems for easy access and low personal requirements | Web based systems are automated systems that enhances information sharing, mutual trust among actors and requires less manpower | Balcik *et al.* (2010), Schulz and Blecken (2010) |
| S12 | Easy to use information sharing and communication tools | Communication tools are the medium used to communicate messages to the target audience. They are easy to use and are required to facilitate information sharing | Balcik *et al.* (2010), Schulz and Blecken (2010) |
| S13 | Feedback mechanism to facilitate learning from prior experiences | A feedback mechanism refers to learning from the mistakes of earlier relief operations so they will not be repeated | Balcik *et al.* (2010), Ponomarov and Holcomb (2009) |
| S14 | Long-term focussed planning instead of short term | Long-term planning is essential for establishing the responsibilities of actors so that system wide improvements can be made | Schulz and Blecken (2010), Kovacs and Spens (2007), Natarajarathinam *et al.* (2009), Pettit and Beresford (2005), Agostinho (2013), Moshtari and Gonçalves (2011), Maiers *et al.* (2005) |
| S15 | Effective policy for coordination | Coordination policy refers to guidelines that promote the interaction among HSC actors in order to enhance coordination | Kleindorfer and Saad (2005) |

**Table III.**

required to incorporate the lessons learned from prior disasters (Balcik *et al.*, 2010; Ponomarov and Holcomb, 2009).

## 3. Methodology

In this study, an integrated framework of fuzzy logic, AHP and TOPSIS has been used to explore, propose and prioritize solutions to enhance the coordination of HSC in the Indian context. The proposed methodology consists of three phases (Patil and Kant, 2014). In the first phase, barriers and solutions to overcome the barriers were explored by brainstorming sessions with experts. In the second phase, fuzzy AHP estimated the weight of barriers, and in the third phase fuzzy TOPSIS prioritized solutions to enhance HSC coordination. The research framework is given in Figure 1.

Although multi-criteria decision making (MCDM) can fulfill the objective of the study, the MCDM process can be improved with fuzzy techniques, since they are best suited to handle imprecise and uncertain data and factors (Zadeh, 1965; Zimmermann, 2001). Several important definitions of fuzzy logic are given below:

*Definition 1.* A fuzzy set $\widetilde{A}$ is subset of a universe of discourse $X$, which is a set of ordered pairs and is characterized by a membership function $u_{\widetilde{A}}(x)$ representing a mapping $u_{\widetilde{A}} : x \to [0, 1]$. The function value of $u_{\widetilde{A}}(x)$ for the fuzzy set $\widetilde{A}$ is called the membership value of $x$ in $\widetilde{A}$, which represents the degree of truth that $x$ is an element of the fuzzy set $\widetilde{A}$. It is assumed that $u_{\widetilde{A}}(x)$ € [0,1], where $u_{\widetilde{A}}(x) = 1$ reveals that $x$ completely belongs to $\widetilde{A}$, while $u_{\widetilde{A}}(x) = 0$ indicates that $x$ does not belong to the fuzzy set $\widetilde{A}$:

$$\widetilde{A} = \left\{ \left(x, u_{\widetilde{A}}(x)\right) \right\}, \;\; x \text{ € } X \tag{1}$$

where $u_{\widetilde{A}}(x)$ is the membership function and $X = \{x\}$ represents a collection of elements $x$:

*Definition 2.* A fuzzy number $\widetilde{A}$, if it belongs to a triangular fuzzy number like Figure 2, it should satisfy the following properties:

- $u_{\widetilde{A}}(x) = 0$, for all $x$ € $(-\infty,1)$;
- $u_{\widetilde{A}}(x)$ is strictly increasing on $[1,m]$;
- $u_{\widetilde{A}}(x) = 1$, for $x = m$;
- $u_{\widetilde{A}}(x)$ is strictly decreasing on $[m,u]$; and
- $u_{\widetilde{A}}(x) = 0$, for all $x$ € $(u,\infty)$.

*Definition 3.* Let $\widetilde{A}$ be a triangular fuzzy number $(l,m,u)$ and its membership function can be defined as:

$$u_{\widetilde{A}}(x) = \begin{cases} \frac{x-l}{m-l} & l \leqslant x \leqslant m \\ \frac{u-x}{u-m} & m \leqslant x \leqslant u \\ 0 & otherwise \end{cases} \tag{2}$$

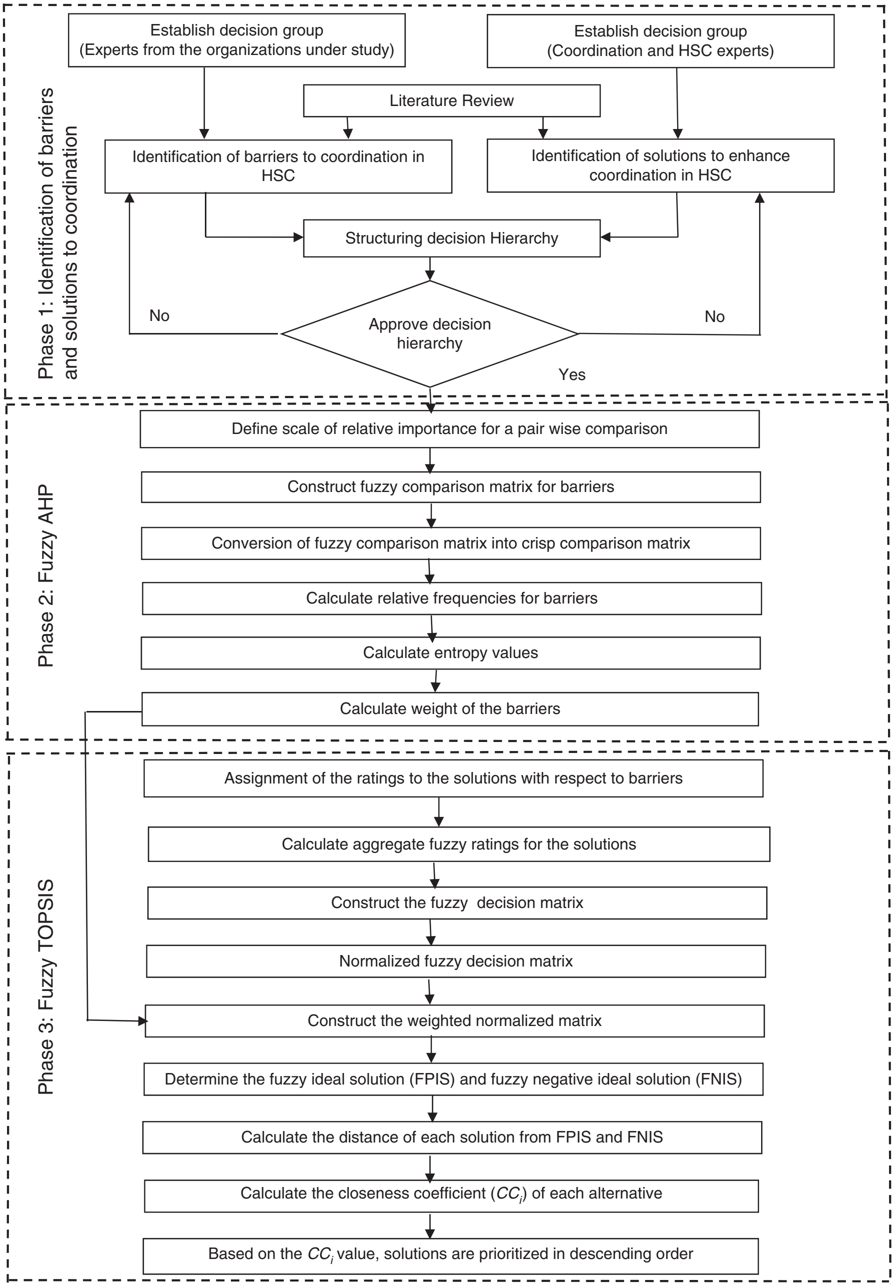
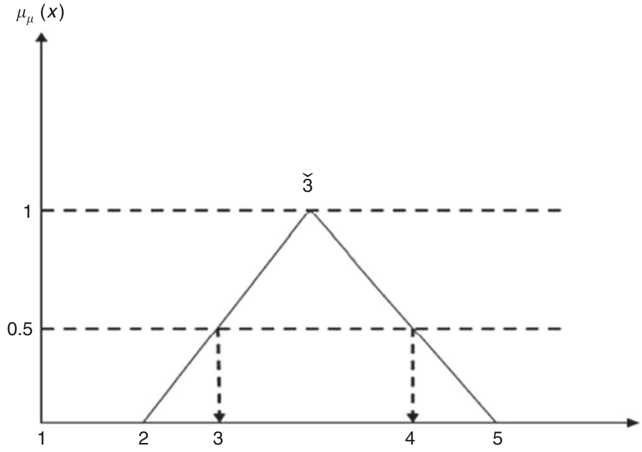



**Figure 1.**
Research design




**Note:** $\alpha_{0.5} = (2,3,4) = [1.5,5]$

**Figure 2.**
$\alpha$ cut operation on a triangular fuzzy number

*Definition 4.* The $\alpha$-cut of the fuzzy set $\widetilde{A}$ of the universe of discourse $X$ is defined as:

$$A_\alpha = \left\{x \in X, u_{\widetilde{A}}(x) \geqslant \alpha\right\} \text{where } \alpha \in [0,1] \tag{3}$$

*Definition 5.* Suppose $a = (a_1,a_2,a_3)$ and $b = (b_1,b_2,b_3)$ are two TFNs, the distance between them is calculated as:

$$d_v\left(\widetilde{a},\widetilde{b}\right) = \sqrt{\frac{1}{3}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\right]} \tag{4}$$

*Definition 6.* If $\widetilde{A}_1 = (l_1, m_1, u_1)$ and $\widetilde{A}_2 = (l_2, m_2, u_2)$ are representing two traingular fuzzy numbers then algebric operations can be expressed as follows:

$$\begin{aligned}\widetilde{A}_1(+)\,\widetilde{A}_1 &= (l_1, m_1, u_1) \textit{ and } \widetilde{A}_2 = (l_2, m_2, u_2)\\ &= (l_1 + l_2), (m_1 + m_2) \textit{ and } \widetilde{A}_2 = (u_1 + u_2)\end{aligned} \tag{5}$$

$$\begin{aligned}\widetilde{A}_1(-)\,\widetilde{A}_1 &= (l_1, m_1, u_1) \textit{ and } \widetilde{A}_2 = (l_2, m_2, u_2)\\ &= (l_1 - l_2), (m_1 - m_2) \textit{ and } \widetilde{A}_2 = (u_1 - u_2)\end{aligned} \tag{6}$$

$$\begin{aligned}\widetilde{A}_1(\times)\,\widetilde{A}_1 &= (l_1, m_1, u_1) \textit{ and } \widetilde{A}_2 = (l_2, m_2, u_2)\\ &= (l_1 l_2), (m_1 m_2) \textit{ and } \widetilde{A}_2 = (u_1 u_2)\end{aligned} \tag{7}$$

$$\begin{aligned}\widetilde{A}_1(/)\,\widetilde{A}_1 &= (l_1, m_1, u_1) \textit{ and } \widetilde{A}_2 = (l_2, m_2, u_2)\\ &= \left(l_1/l_2\right), \left(m_1/m_2\right) \textit{ and } \widetilde{A}_2 = \left(u_1/u_2\right)\end{aligned} \tag{8}$$

$$A(\times)\widetilde{A}_1 = (\alpha l_1, \alpha m_1, \alpha u_1) \textit{ where } \alpha \geqslant 0 \tag{9}$$

$$\widetilde{A}_1^{-1} = (l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \quad (10)$$

*3.1 Fuzzy AHP*

AHP is a quantitative technique for MCDM developed by Satty in 1980. In classical AHP, individual preferences are assigned with crisp values and cannot handle uncertainty and subjective judgments, so there is a need to use fuzzy sets in decision-making (Govindan and Murugesan, 2011; Kristianto *et al.*, 2014; Chang, 1996; Choudhary and Shankar, 2012; Bozbura *et al.*, 2007; Kahraman *et al.*, 2003; Kwong and Bai, 2002) pioneered by Zadeh (1965). Therefore, fuzzy AHP methodology extends Satty's AHP by combining it with fuzzy set theory to solve MCDM. The fuzzy AHP method is explained as follows:

Step 1. Defining a scale of relative importance used in the pair wise comparison matrix. The TFNs, $\widetilde{1}$-$\widetilde{9}$, are used in F-AHP as compared to AHP as given in Table IV. The membership function for corresponding TFNs are given in Figure 3.

Step 2. Construct the fuzzy comparison matrix.

The pair wise comparisons for the main criteria and sub criteria were made by using TFNs as given in Table IV. The arithmetic mean of the pair wise comparisons from different experts has been utilized to form single fuzzy

| Intensity of importance | Fuzzy number | Linguistic variable | Membership function | Reciprocal membership function |
|---|---|---|---|---|
| 1 | $\widetilde{1}$ | Equally important/preferred | (1, 1, 3) | (1/3, 1, 1) |
| 3 | $\widetilde{3}$ | Weakly important/preferred | (1, 3, 5) | (1/5, 1/3, 1) |
| 5 | $\widetilde{5}$ | Strongly more important/preferred | (3, 5, 7) | (1/7, 1/5, 1/3) |
| 7 | $\widetilde{7}$ | Very strongly important/preferred | (5, 7, 9) | (1/9, 1/7, 1/5) |
| 9 | $\breve{9}$ | Extremely more important/ preferred | (7, 9, 11) | (1/11, 1/9,1/7) |

**Sources:** Kahraman (2008)

**Table IV.** Triangular fuzzy conversion scale

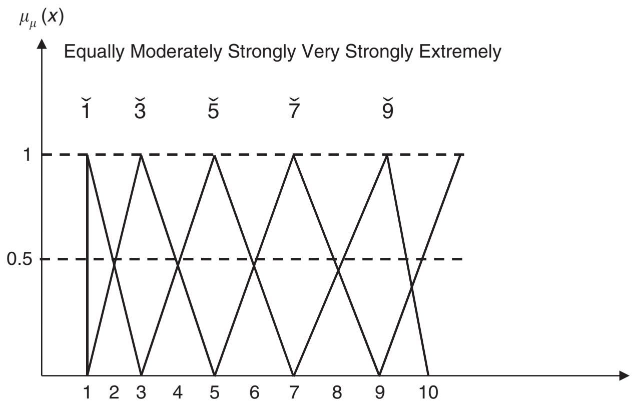



**Figure 3.** Fuzzy membership function for criteria

comparison matrix.

$$\widetilde{\boldsymbol{A}} = \begin{vmatrix} 1 & \widetilde{\boldsymbol{a}}_{12} & \dots & \widetilde{\boldsymbol{a}}_{1n} \\ \vdots & 1 & \dots & \widetilde{\boldsymbol{a}}_{2n} \\ \vdots & \dots & 1 & \vdots \\ \widetilde{\boldsymbol{a}}_{n1} & \dots & \dots & 1 \end{vmatrix} \tag{11}$$

$\widetilde{a}_{ij}$ is the relationship of component i to component $j$. If $i$ equals to $j$ then $\widetilde{a}_{ij} = 1$ and $a$ reciprocal value is assigned for the relationship of component $j$ to component $i$, i.e. $1/\check{\boldsymbol{A}}_{ij}$.

Step 3. Converting the fuzzy comparison matrix into a crisp comparison matrix.

The alpha cut method, proposed by Adamo (1980) has been used to rank fuzzy numbers. This method will convert a single fuzzy number to a set of interval values. For example, $\alpha = 0.8$ will yield $\alpha_{0.8} = (1.5, 5)$ by using Equation (12) (see Figure 4). The $i$ index of optimism 0.5 (a linear convex combination) as defined in Equation (13) (Lee *et al.*, 1999), was used to calculate the degree of satisfaction for the judgment matrix. Finally, Equations (12) and (13) have been used to arrive at crisp comparison matrix from a set of interval values.

$$\widetilde{A}_\alpha = \begin{bmatrix} [a^\alpha_{11l}, a^\alpha_{1lu}] & \dots & \dots & [a^\alpha_{1nl}, a^\alpha_{1nu}] \\ \vdots & \dots & \dots & \vdots \\ \vdots & \dots & \dots & \vdots \\ [a^\alpha_{n1l}, a^\alpha_{nlu}] & \dots & \dots & [a^\alpha_{nnl}, a^\alpha_{nnu}] \end{bmatrix}$$

$$\text{Where} \quad \widetilde{A}_\alpha = [a^\alpha_L, a^\alpha_R] = [(a_2 - a_1)\alpha + a_1,\ (a_3 - a_2)\alpha + a_3] \tag{12}$$

$$\widetilde{a}^\alpha_{ij} = \mu a^\alpha_{iju} + (1-\mu) a^\alpha_{iju} \text{ where } 0 < \mu \leqslant 1 \tag{13}$$

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ \vdots & 1 & \dots & a_{2n} \\ \vdots & \dots & 1 & \vdots \\ a_{n1} & \dots & \dots & 1 \end{bmatrix} \tag{14}$$

Step 4. Calculate relative frequencies.

The relative frequency is calculated by the following equation:

$$\begin{bmatrix} \frac{a_{11}}{S_1} & \frac{a_{12}}{S_1} & \dots & \frac{a_{1n}}{S_1} \\ \vdots & 1 & \dots & \dots \\ \vdots & \dots & \dots & \vdots \\ \frac{a_{n1}}{S_n} & \frac{a_{n2}}{S_n} & \dots & \frac{a_{nn}}{S_n} \end{bmatrix} = \begin{bmatrix} 1 & f_{12} & \dots & f_{1n} \\ \vdots & \vdots & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ f_{n1} & f_{n2} & \dots & f_{nn} \end{bmatrix} \tag{15}$$

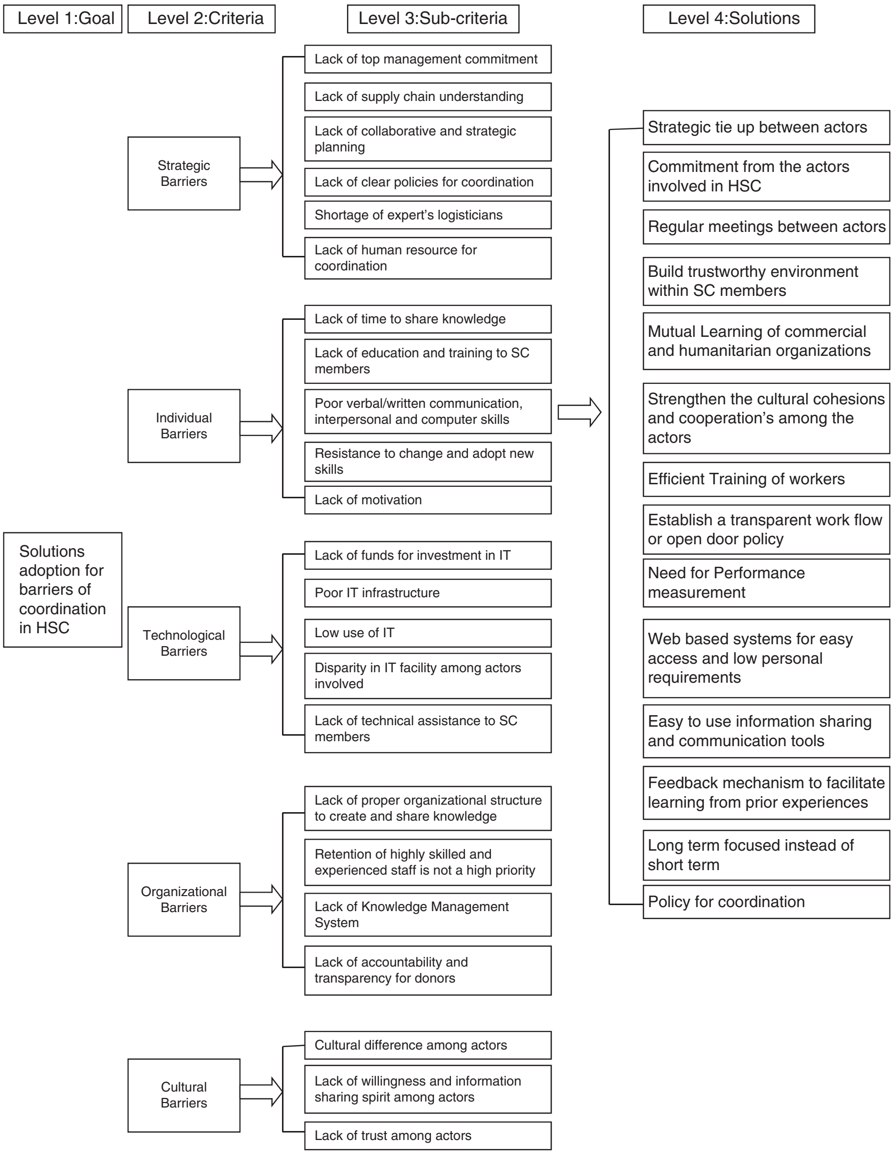



**Figure 4.**
Decision hierarchy

$$\text{where } S_k = \sum_{j=1}^{n} a_{kj} \tag{16}$$

Step 5. Calculate entropy value.
The entropy values are calculated by using the relative frequencies and the following equation:

$$H_1 = -\sum_{j=1}^{n} (f_{ij}) log_2 (f_{1j}) \tag{17}$$

$$H_2 = -\sum_{j=1}^{n} (f_{2j}) log_2 (f_{2j}) \tag{18}$$

$$H_3 = -\sum_{j=1}^{n} (f_{nj}) log_2 (f_{nj}) \tag{19}$$



where $H_i$ is $i$th entropy value.

Step 6. Calculation of weights of the criteria.

The resultant aggregate weight of each criterion will be calculated by normalizing the entropy values obtained in step 5.

### *3.2 Fuzzy TOPSIS*

In 1981, Hwang and Yoon proposed TOPSIS, which is one of the MCDM methods. It is based on the concept that a selected attribute should have the least and largest distance from the positive ideal solution (PIS) and the negative ideal solution (NIS), respectively (Shih *et al.*, 2007). In the classical TOPSIS method, individual preferences are represented with crisp values. However, in order to consider the impreciseness and uncertainty of real life cases, linguistic variables can be used instead of crisp value (Büyüközkan *et al.*, 2008; Shaw *et al.*, 2013; Choudhary and Shankar, 2012; Chu, 2002; Önüt and Soner, 2008; Wang and Elhag, 2006; Chen and Tsao, 2008; Dağdeviren *et al.*, 2009). The fuzzy TOPSIS method is explained as follows.

Step 1. Choose the linguistic rating values for the alternative with respect to criteria on the basis of scale given in Table V.

Step 2. Calculate aggregate fuzzy ratings for the alternatives.

If the fuzzy ratings of all experts are described as TFN $\widetilde{R_k} = (a_k, b_k, c_k)$, $k = 1,2,3, \ldots K$ then the aggregated fuzzy rating is given where:

$$a = min_k\{a_k\},\ b = \frac{1}{k}\sum_{k=1}^{k} b_k,\ c = max_k\{C_k\} \tag{20}$$

Step 3. Construct the fuzzy decision matrix.

The fuzzy decision matrix for the alternatives is constructed as follows:

$$\begin{array}{c} A_1 \\ A_2 \\ \\ A_n \end{array} \begin{vmatrix} \widetilde{\boldsymbol{x}}_{11} & \widetilde{\boldsymbol{x}}_{12} & \ldots & \ldots & \widetilde{\boldsymbol{x}}_{1n} \\ \widetilde{\boldsymbol{x}}_{21} & \widetilde{\boldsymbol{x}}_{22} & \ldots & \ldots & \widetilde{\boldsymbol{x}}_{2n} \\ \vdots & \ldots & \ldots & \ldots & \vdots \\ \widetilde{\boldsymbol{x}}_{m1} & \widetilde{\boldsymbol{x}}_{m2} & \ldots & \ldots & \widetilde{\boldsymbol{x}}_{mn} \end{vmatrix} \tag{21}$$

where $i = 1, 2, 3, \ldots \ldots m; j = 1,2, \ldots \ldots n.$

**Table V.**
Linguistic variables for solutions ratings

| Linguistic variables | Corresponding TFN |
|---|---|
| Very poor (VP) | (1,1,3) |
| Poor (P) | (1,3,5) |
| Medium (M) | (3,5,7) |
| Good (G) | (5,7,9) |
| Very good (VG) | (7,9,11) |

Step 4. Normalized fuzzy decision matrix.
The normalized fuzzy decision matrix is given by:

$$\widetilde{R} = \left[r_{ij}\right]_{mxn}, \text{where } i = 1, 2, \ldots m; \; j = 1, 2, \ldots, n \tag{22}$$

where:

$$\widetilde{r}_{ij} = \left(\frac{\widetilde{a}_{ij}}{C_j^*}, \frac{\widetilde{b}_{ij}}{C_j^*}, \frac{\widetilde{c}_{ij}}{C_j^*}\right) \; and \; c_j^* = \max_i \left\{c_{ij}\right\} \; (benefit \; criteria) \tag{23}$$

$$\widetilde{r}_{ij} = \left(\frac{a_j^-}{C_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \; and \; a_j^- = \min_i \left\{a_{ij}\right\} \; \{cost \; criteria\} \tag{24}$$

Step 5. Construct the weighted normalized matrix.
The weighted normalized matrix for criteria is computed by multiplying the weights ($W_j$) of evaluation criteria with the normalized fuzzy decision matrix:

$$\widetilde{V} = \left[\widetilde{v}_{ij}\right]_{mxn} \; i = 1, 2, \ldots m; \; j = 1, 2, \ldots, n, where \; \widetilde{v}_{ij} = r_{ij} \times W_j \tag{25}$$

Step 6. Determine the fuzzy (PIS) and fuzzy (NIS).
The FPIS and FNIS of the alternatives is computed as follows:

$$A^* = \left(\widetilde{v}_1^{\alpha}, \widetilde{v}_2^{\alpha}, \ldots\ldots \widetilde{v}_n^{\alpha}\right) \text{ where } \widetilde{v}_j^* = \left(\widetilde{c}_j^*, \widetilde{c}_j^*, \widetilde{c}_j^*\right) \text{ and } c_1^* = \max_i\{\widetilde{c}_{ij}\} \tag{26}$$

$$A^- = \left(\widetilde{v}_1^-, \widetilde{v}_2^-, \ldots\ldots \widetilde{v}_n^-\right) \text{ where } \widetilde{v}_j^- = \left(\widetilde{a}_j^-, \widetilde{a}_j^-, \widetilde{a}_j^-\right) \text{ and } a_j^- = \max_i\{\widetilde{a}_{ij}\} \tag{27}$$

$$\forall i = 1, 2, \ldots, m; \; j = 1, 2, \ldots n$$

Step 7. Calculate the distance of each alternative from FPIS and FNIS:

$$d_i^+ = \sum_{j=1}^{n} dv\left(v_{\widetilde{ij}}, v_j^*\right), \; i = 1, 2, \ldots m \tag{28}$$

$$d_i^- = \sum_{j=1}^{n} dv\left(v_{\widetilde{ij}}, v_j^*\right), \; i = 1, 2, \ldots m \tag{29}$$

Step 8. Calculate the closeness coefficient ($CC_i$) of each alternative.
The closeness coefficient of each alternative is calculated as:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{30}$$

Step 9. Based on the $CC_i$ value, strategies are prioritized in descending order.

## 4. Application of integrated fuzzy AHP-TOPSIS framework

The integrated fuzzy AHP-TOPSIS framework can prioritize solutions to overcome HSC coordination barriers. The integrated framework consists of three phases provided in the methodology section and its application is explained as follows.

*4.1 Problem description*

Numerous examples cite low coordination among actors negatively affects the efficiency of relief activities. Chandes and Pache (2010) also supported that humanitarian actors should "learn how to collaborate and co-manage relief chains" to enhance the performance, which has "dramatic consequences for stricken populations." Therefore, barriers to coordination in HSCM are important, relevant and to be remove on priority. Coordination in relief activities was affected by various factors as explained in Table II and since it is not possible to improve all factors at the same time it is necessary to prioritize solutions and implement them in a step wise manner.

*4.2 Case analysis*

Phase 1: identification of barriers and solutions to overcome barriers of coordination in HSC.

In this phase, the decision hierarchy is formed to explore the barriers and propose solutions to overcome the barriers to enhance the coordination in HSC. In this study, 23 barriers under five major criteria and 15 solutions (refer Table III) were identified through a literature review and intensive discussion with experts (comprising of SC and coordination expert) who were actively involved in the relief activities in Uttarakhand disaster. The decision hierarchy consist of four levels; the overall goal of the decision process determined as "Solutions adoption for barriers of coordination in HSC" is at the first level. The second level consists of major criteria, the third level is the sub criteria and the fourth level consists of solutions to overcome these barriers (refer Figure 4).

Phase 2: calculate the weight of the barriers to coordination in HSC by fuzzy AHP.

In this phase pair wise comparison matrix, the criteria and sub criteria were constructed from the scale given in Table IV. The pair wise comparison matrixes of the criteria and sub criteria are given in Tables VI-XI. The results were calculated (as explained in the previous section) from the pair wise comparison matrix (refer Tables VI-XI) given in Table XII.

**Table VI.**
A pair wise comparison matrix of the major criteria

| | SB | IB | OB | TB | CB |
|---|---|---|---|---|---|
| SB | $\tilde{1}$ | $\tilde{5}$ | $\breve{9}$ | $\tilde{7}$ | $\tilde{3}$ |
| IB | $\tilde{5}^{-1}$ | $\tilde{1}$ | $\tilde{3}$ | $\tilde{3}$ | $\tilde{3}^{-1}$ |
| OB | $\tilde{9}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{1}$ | $\tilde{3}$ | $\tilde{3}^{-1}$ |
| TB | $\tilde{7}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{1}$ | $\tilde{7}^{-1}$ |
| CB | $\tilde{3}^{-1}$ | $\tilde{3}$ | $\tilde{3}$ | $\tilde{7}$ | $\tilde{1}$ |

**Table VII.**
A pair wise comparison matrix of the management barriers (MBs)

| | SB1 | SB2 | SB3 | SB4 | SB5 | SB6 |
|---|---|---|---|---|---|---|
| SB1 | $\tilde{1}$ | $\tilde{3}^{-1}$ | $\tilde{3}$ | $\tilde{5}$ | $\tilde{3}$ | $\tilde{7}$ |
| SB2 | $3$ | $\tilde{1}$ | $\tilde{3}$ | $\breve{9}$ | $\tilde{3}$ | $\breve{9}$ |
| SB3 | $\tilde{3}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{1}$ | $\tilde{5}$ | $\tilde{3}$ | $\tilde{7}$ |
| B4 | $\tilde{5}^{-1}$ | $\tilde{9}^{-1}$ | $\tilde{5}^{-1}$ | $\tilde{1}$ | $\tilde{3}^{-1}$ | $\tilde{3}^{-1}$ |
| SB5 | $\tilde{3}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{3}$ | $\tilde{1}$ | $\tilde{3}$ |
| SB6 | $\tilde{7}^{-1}$ | $\tilde{9}^{-1}$ | $\tilde{7}^{-1}$ | $\tilde{3}$ | $\tilde{3}^{-1}$ | $\tilde{1}$ |

Phase 3: evaluation of the strategies to enhance coordination in HSC and determines the final rank by fuzzy TOPSIS.

The fuzzy evaluation matrix was formed by using linguistic variables from an expert panel (Table V). It was constructed by comparing the solutions under each of the barriers separately (refer Table XIII). Then linguistic terms were converted into corresponding TFN and a fuzzy evaluation matrix was constructed (refer Table XIV, dueto space limitation, linguistic evaluation matrix and a fuzzy evaluation matrix of expert 1 is only given here).

Aggregate fuzzy weights of the alternatives were calculated using Equation (20) and presented in Table XV. In this study all the criteria are the barriers, and as per goal minimization, these barriers are termed as cost criteria and normalization performed by Equation (24) (refer Table XVI).In the next step, the weighted evaluation matrix was constructed using Equation (25) as shown in Table XVII. The FPIS ($A^*$) and FNIS ($A^-$) $v^*$ as $= (0, 0, 0)$ and $v^- = (1, 1, 1)$ for all these barriers as they are cost criteria. The final

| | IB1 | IB2 | IB3 | IB4 | IB5 |
|---|---|---|---|---|---|
| IB1 | $\tilde{1}$ | $\tilde{3}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{3}^{-1}$ |
| IB2 | $\tilde{3}$ | $\tilde{1}$ | $\tilde{5}$ | $\tilde{7}$ | $\tilde{3}$ |
| IB3 | $\tilde{3}$ | $\tilde{5}^{-1}$ | $\tilde{1}$ | $\tilde{3}$ | $\tilde{3}$ |
| IB4 | $\tilde{3}$ | $\tilde{7}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{1}$ | $\tilde{3}$ |
| IB5 | $\tilde{3}$ | $3_1$ | $\tilde{3}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{1}$ |

**Table VIII.** A pair wise comparison matrix of the individual barriers (IBs)

| | OB1 | OB2 | OB3 | OB4 |
|---|---|---|---|---|
| OB1 | $\tilde{1}$ | $\tilde{5}$ | $\tilde{5}$ | $\breve{9}$ |
| OB2 | $\tilde{5}^{-1}$ | $\tilde{1}$ | $\tilde{5}^{-1}$ | $\tilde{3}$ |
| OB3 | $\tilde{5}^{-1}$ | $\tilde{5}$ | $\tilde{1}$ | $\breve{9}$ |
| OB4 | $\tilde{9}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{9}^{-1}$ | $\tilde{1}$ |

**Table IX.** A pair wise comparison matrix of the organizational barriers (OBs)

| | TB1 | TB2 | TB3 | TB4 | TB5 |
|---|---|---|---|---|---|
| TB1 | $\tilde{1}$ | $\breve{9}$ | $\tilde{5}$ | $\tilde{7}$ | $\tilde{5}$ |
| TB2 | $\tilde{9}^{-1}$ | $\tilde{1}$ | $\tilde{7}$ | $\tilde{3}$ | $\tilde{3}$ |
| TB3 | $\tilde{5}^{-1}$ | $\tilde{7}_1$ | $\tilde{1}$ | $\tilde{3}^{-1}$ | $\tilde{3}^{-1}$ |
| TB4 | $\tilde{7}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{3}$ | $\tilde{1}$ | $\tilde{3}$ |
| TB5 | $\tilde{5}^{-1}$ | $\tilde{3}^{-1}$ | $\tilde{3}$ | $\tilde{3}^{-1}$ | $\tilde{1}$ |

**Table X.** A pair wise comparison matrix of the technological barriers (TBs)

| | CB1 | CB2 | CB3 |
|---|---|---|---|
| CB1 | $\tilde{1}$ | $\tilde{3}$ | $\tilde{7}$ |
| CB2 | $\tilde{3}^{-1}$ | $\tilde{1}$ | $\tilde{5}$ |
| CB3 | $\tilde{7}^{-1}$ | $\tilde{5}^{-1}$ | $\tilde{1}$ |

**Table XI.** A pair wise comparison matrix of the cultural barriers (CBs)

| Major criterion | Major criterion weight (MW) | Notation | Ratio weight (RW) | Final weight = MW×RW | Rank |
|---|---|---|---|---|---|
| Strategic barriers | 0.2239527 | SB1 | 0.179784733 | 0.040263276 | 13 |
| | | SB2 | 0.184360569 | 0.041288047 | 10 |
| | | SB3 | 0.162406479 | 0.036371369 | 18 |
| | | SB4 | 0.172862067 | 0.038712927 | 14 |
| | | SB5 | 0.16808235 | 0.037642496 | 15 |
| | | SB6 | 0.132503802 | 0.029674584 | 22 |
| Individual barriers | 0.200009419 | IB1 | 0.214897982 | 0.042981621 | 9 |
| | | IB2 | 0.216038656 | 0.043209766 | 8 |
| | | IB3 | 0.205920035 | 0.041185947 | 11 |
| | | IB4 | 0.183047162 | 0.036611157 | 17 |
| | | IB5 | 0.180096166 | 0.03602093 | 19 |
| Organizational barriers | 0.197466889 | OB1 | 0.30420143 | 0.06006971 | 4 |
| | | OB2 | 0.226737325 | 0.044773114 | 7 |
| | | OB3 | 0.233543876 | 0.046117183 | 6 |
| | | OB4 | 0.235517369 | 0.046506882 | 5 |
| Technological barriers | 0.17477067 | TB1 | 0.235632098 | 0.04118158 | 12 |
| | | TB2 | 0.167058026 | 0.029196843 | 23 |
| | | TB3 | 0.211425746 | 0.036951019 | 16 |
| | | TB4 | 0.199102996 | 0.034797364 | 20 |
| | | TB5 | 0.186781135 | 0.032643864 | 21 |
| Cultural barriers | 0.203800322 | CB1 | 0.392380386 | 0.079967249 | 1 |
| | | CB2 | 0.303393526 | 0.061831698 | 3 |
| | | CB3 | 0.304226088 | 0.062001375 | 2 |

**Table XII.** Weight of barriers of coordination in HSC

results are summarized in the Table XVIII. Based on the $CC_i$value, solutions are ranked in descending order.

## 5. Finding and discussion

It is difficult to say which solution is the most important for enhancing the coordination in HSCM, but prioritizing solutions using an integrated framework of fuzzy AHP-TOPSIS made it more comprehensive and systematic. This integrated framework of fuzzy AHP and fuzzy TOPSIS was made to enhance the coordination in HSCM, which will bring drastic changes in terms of the effective and efficient management of relief activities. A literature review and brainstorming sessions with experts helped to identify 23 barriers and 15 solutions. Fuzzy AHP was used to estimate the weight of barriers and the solutions were prioritized based on these weight with fuzzy TOPSIS.

The result of the integrated fuzzy AHP-TOPSIS framework is shown in Table XVIII. The evaluation of the solutions for enhancing the coordination of the HSC in the Indian context was realized and according to the $CC_i$ value ranking, the solutions are S14-S2-S9-S13-S15-S6-S1-S4-S8-S10-S12-S5-S10-S11-S7 from the most important to the least. Long-term focussed planning instead of short-term planning is the highest rank solution as it is essential for establishing the responsibilities of actors so that system wide improvements can be made, while commitment from all the actors involved in relief activities is at the second rank and establishing a transparent work flow or open door policy in the organizations is ranked third. Hence, actors of the HSCM in India

**Table XIII.** Linguistic scale evaluation matrix for the solutions (Expert 1)

| | SB1 | SB2 | SB3 | SB4 | SB5 | SB6 | IB1 | IB2 | IB3 | IB4 | IB5 | TB1 | TB2 | TB3 | TB4 | TB5 | OB1 | OB2 | OB3 | OB4 | CB1 | CB2 | CB3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | VP | G | VP | P | G | P | VP | G | G | G | M | M | M | M | G | G | M | G | M | G | M | G | G |
| S2 | G | VP | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G | G |
| S3 | VP | M | M | VP | M | VP | P | M | P | G | VP | VP | G | VG | G | G | G | VG | VG | VG | G | VG | VP |
| S4 | P | G | VP | P | G | M | VP | G | M | G | G | M | P | M | M | M | G | P | M | G | G | G | G |
| S5 | VP | P | VG | VP | M | P | P | M | M | M | G | G | P | P | VP | VP | G | P | M | VG | G | G | VG |
| S6 | P | VP | VP | P | G | M | P | G | G | G | G | G | G | G | G | G | M | M | G | G | M | G | G |
| S7 | VP | P | P | P | P | P | VP | P | G | G | M | G | M | G | M | G | M | M | P | M | G | G | G |
| S8 | VP | M | P | M | VG | M | M | VG | VG | G | VG | VP | M | G | G | VG | G | G | G | M | G | G | M |
| S9 | M | G | G | G | G | M | VP | G | M | G | VG | VG | G | M | M | P | VG | G | VG | VG | G | VG | G |
| S10 | M | G | G | M | M | VP | VP | P | P | P | VG | VG | G | VG | VG | G | G | VP | M | VG | VP | VP | M |
| S11 | VP | M | VG | P | M | G | M | M | M | G | M | VP | M | VG | G | P | G | VP | G | G | P | P | M |
| S12 | P | M | M | M | P | G | VG | G | G | G | G | P | P | G | VG | G | G | P | M | G | M | M | M |
| S13 | G | G | M | M | G | G | G | G | G | G | G | G | G | G | G | G | VG | G | VG | VG | G | M | P |
| S14 | G | VP | VG | VG | VG | VG | M | G | G | G | G | G | G | G | G | G | G | G | VG | G | G | M | G |
| S15 | G | G | VG | VG | P | M | M | G | G | M | M | G | G | M | M | VG | G | P | M | M | G | M | G |

Table XIV.
Fuzzy evaluation matrix for solutions (Expert 1)

| | SB1 | SB2 | TB1 | TB2 | CB2 | CB3 |
|---|---|---|---|---|---|---|
| S1 | (1, 1, 3) | (5, 7, 9) | (3, 5, 7) | (3, 5, 7) | (5, 7, 9) | (5, 7, 9) |
| S2 | (5, 7, 9) | (1, 1, 3) | (5, 7, 9) | (5, 7, 9) | (5, 7, 9) | (5, 7, 9) |
| S3 | (1, 1, 3) | (3, 5, 7) | (1, 1, 3) | (5, 7, 9) | (7, 9, 11) | (1, 1, 3) |
| S4 | (1, 3, 5) | (5, 7, 9) | (3, 5, 7) | (1, 3, 5) | (5, 7, 9) | (5, 7, 9) |
| S5 | (1, 1, 3) | (1, 3, 5) | (5, 7, 9) | (1, 3, 5) | (5, 7, 9) | (7, 9, 11) |
| S6 | (1, 3, 5) | (1, 1, 3) | (5, 7, 9) | (5, 7, 9) | (5, 7, 9) | (5, 7, 9) |
| S7 | (1, 1, 3) | (1, 3, 5) | (5, 7, 9) | (3, 5, 7) | (5, 7, 9) | (5, 7, 9) |
| S8 | (1, 1, 3) | (3, 5, 7) | (1, 1, 3) | (3, 5, 7) | (5, 7, 9) | (3, 5, 7) |
| S9 | (3, 5, 7) | (5, 7, 9) | (7, 9, 11) | (5, 7, 9) | (7, 9, 11) | (5, 7, 9) |
| S10 | (3, 5, 7) | (5, 7, 9) | (7, 9, 11) | (5, 7, 9) | (1, 1, 3) | (3, 5, 7) |
| S11 | (1, 1, 3) | (3, 5, 7) | (1, 1, 3) | (3, 5, 7) | (1, 3, 5) | (3, 5, 7) |
| S12 | (1, 3, 5) | (3, 5, 7) | (1, 3, 5) | (1, 3, 5) | (3, 5, 7) | (3, 5, 7) |
| S13 | (5, 7, 9) | (5, 7, 9) | (5, 7, 9) | (5, 7, 9) | (3, 5, 7) | (1, 3, 5) |
| S14 | (5, 7, 9) | (1, 1, 3) | (5, 7, 9) | (5, 7, 9) | (3, 5, 7) | (5, 7, 9) |
| S15 | (5, 7, 9) | (5, 7, 9) | (5, 7, 9) | (5, 7, 9) | (3, 5, 7) | (5, 7, 9) |

Table XV.
Aggregate fuzzy decision matrix for solutions

| | SB1 | SB2 | CB2 | CB3 |
|---|---|---|---|---|
| S1 | (1, 5.6, 11) | (5, 7.6, 11) | (5, 7, 9) | (5, 7.6, 11) |
| S2 | (5, 8.33, 11) | (1, 5.6, 11) | (5, 7, 9) | (5, 7.6, 11) |
| S3 | (1, 5.6, 11) | (3, 7, 11) | (7, 9, 11) | (1, 6.3, 11) |
| S4 | (1, 6.3, 11) | (5, 7.6, 11) | (5, 7, 9) | (5, 7.6, 11) |
| S5 | (1, 5.6, 11) | (1, 6.3, 11) | (5, 7.6, 11) | (7, 9, 11) |
| S6 | (1, 6.3, 11) | (1, 5, 9) | (5, 7, 9) | (5, 8.3, 11) |
| S7 | (1, 5, 9) | (1, 5.6, 9) | (5, 7, 9) | (3, 6.3, 9) |
| S8 | (1, 5, 9) | (3, 7, 11) | (5, 7, 9) | (3, 5, 7) |
| S9 | (3, 7, 11) | (5, 7.6, 11) | (7, 9, 11) | (5, 8.3, 11) |
| S10 | (3, 6.3, 9) | (5, 8.3, 11) | (1, 5, 9) | (3, 6.3, 9) |
| S11 | (1, 4.3, 9) | (3, 5.6, 9) | (1, 7, 11) | (3, 7, 11) |
| S12 | (1, 6.3, 11) | (3, 5.6, 9) | (3, 7, 11) | (3, 6.3, 9) |
| S13 | (5, 8.3, 11) | (5, 7.6, 11) | (3, 7.6, 11) | (1, 6.3, 11) |
| S14 | (5, 7.6, 11) | (1, 5.6, 11) | (3, 7, 11) | (5, 7.6, 11) |
| S15 | (5, 8.3, 11) | (5, 7.6, 11) | (3, 6.3, 9) | (5, 7.6, 11) |

should implement these solutions on a priority basis and the remaining in a stepwise manner as per the ranking.

### *5.1 Sensitivity analysis*

A sensitivity analysis was performed to observe the effect of changes in barrier weights on the evaluation process and ranking of solutions to enhance the coordination of the HSC. In the first 18 experiments, the weight of each barrier was set higher one by one and other set to low and equal values. For example, in experiment 1 the weight of barrier SB1 (WSB1) = 0.70 and the weight of the remaining 22 barriers (WSB2–WCB3) are assumed to be of equal importance, therefore they are allocated equal weight = 0.15. In experiment 19, the weight of all the barriers is equal to 0.15. In experiment 20, the weight of barriers (WSB1–WSB6) = 0.15 and others barriers were weight equal to 0.
It can be seen from Figure 5 that solution rankings significantly changes, when the

| | SB1 | SB2 | CB2 | CB3 |
|---|---|---|---|---|
| S1 | (0.09, 0.176, 1) | (0.09, 0.130, 0.2) | (0.11, 0.142, 0.2) | (0.09, 0.130, 0.2) |
| S2 | (0.09, 0.12, 0.2) | (0.09, 0.176, 1) | (0.11, 0.142, 0.2) | (0.09, 0.130, 0.2) |
| S3 | (0.09, 0.176, 1) | (0.09, 0.142, 0.33) | (0.09, 0.11, 142) | (0.09, 0.157, 1) |
| S4 | (0.09, 0.157, 1) | (0.09, 0.130, 0.2) | (0.11, 0.142, 0.2) | (0.09, 0.130, 0.2) |
| S5 | (0.09, 0.176, 1) | (0.09, 0.157, 1) | (0.09, 0.130, 0.2) | (0.09, 0.11, 0.142) |
| S6 | (0.09, 0.157, 1) | (0.11, 0.2, 1) | (0.11, 0.142, 0.2) | (0.09, 0.130, 0.2) |
| S7 | (0.11, 0.2, 1) | (0.09, 0.176, 1) | (0.11, 0.142, 0.2) | (0.09, 0.12, 0.2) |
| S8 | (0.11, 0.2, 1) | (0.09, 0.142, 0.33) | (0.11, 0.142, 0.2) | (0.11, 0.157, 0.33) |
| S9 | (0.09, 0.143, 0.33) | (0.09, 0.130, 0.2) | (0.09, 0.11, 0.142) | (0.09, 0.12, 0.2) |
| S10 | (0.11, 0.157, 0.33) | (0.09, 0.176, 1) | (0.11, 0.2, 1) | (0.11, 0.157, 0.33) |
| S11 | (0.11, 0.23, 1) | (0.11, 0.176, 0.33) | (0.09, 0.142, 1) | (0.09, 0.142, 0.33) |
| S12 | (0.09, 0.157, 1) | (0.09, 0.176, 1) | (0.09, 0.142, 0.33) | (0.11, 0.157, 0.33) |
| S13 | (0.09, 0.12, 0.2) | (0.09, 0.130, 0.2) | (0.09, 0.130, 0.33) | (0.09, 0.157, 1) |
| S14 | (0.09, 0.130, 0.2) | (0.09, 0.176, 1) | (0.09, 0.142, 0.33) | (0.09, 0.130, 0.2) |
| S15 | (0.09, 0.12, 0.2) | (0.09, 0.130, 0.2) | (0.11, 0.157, 0.33) | (0.09, 0.130, 0.2) |

**Table XVI.** Normalized fuzzy decision matrix for solutions

| | SB1 | SB2 | CB2 | CB3 |
|---|---|---|---|---|
| S1 | (0.0036, 0.007, 0.040) | (0.0037, 0.005, 0.008) | (0.0068, 0.008, 0.012) | (0.0056, 0.008, 0.012) |
| S2 | (0.0036, 0.004, 0.008) | (0.0037, 0.007, 0.041) | (0.0068, 0.008, 0.012) | (0.0056, 0.008, 0.012) |
| S3 | (0.0036, 0.007, 0.040) | (0.0037, 0.005, 0.013) | (0.0056, 0.006, 0.008) | (0.0056, 0.009, 0.062) |
| S4 | (0.0036, 0.006, 0.040) | (0.0037, 0.005, 0.008) | (0.0068, 0.008, 0.012) | (0.0056, 0.008, 0.012) |
| S5 | (0.0036, 0.007, 0.040) | (0.0037, 0.006, 0.041) | (0.0056, 0.008, 0.012) | (0.0056, 0.006, 0.008) |
| S6 | (0.0036, 0.006, 0.040) | (0.0045, 0.008, 0.041) | (0.0068, 0.008, 0.012) | (0.0056, 0.008, 0.012) |
| S7 | (0.0044, 0.008, 0.040) | (0.0045, 0.007, 0.041) | (0.0068, 0.008, 0.012) | (0.0056, 0.007, 0.012) |
| S8 | (0.0044, 0.008, 0.040) | (0.0037, 0.005, 0.013) | (0.0068, 0.008, 0.012) | (0.006, 0.009, 0.020) |
| S9 | (0.0036, 0.005, 0.013) | (0.0037, 0.005, 0.008) | (0.0056, 0.006, 0.008) | (0.0056, 0.007, 0.012) |
| S10 | (0.0044, 0.006, 0.013) | (0.0037, 0.004, 0.008) | (0.0068, 0.012, 0.061) | (0.0068, 0.009, 0.020) |
| S11 | (0.0044, 0.009, 0.040) | (0.0045, 0.007, 0.013) | (0.0056, 0.008, 0.061) | (0.0056, 0.008, 0.020) |
| S12 | (0.0036, 0.006, 0.040) | (0.0045, 0.007, 0.013) | (0.0056, 0.008, 0.020) | (0.0068, 0.009, 0.020) |
| S13 | (0.0036, 0.004, 0.008) | (0.0037, 0.005, 0.008) | (0.0056, 0.008, 0.020) | (0.0056, 0.009, 0.062) |
| S14 | (0.0036, 0.005, 0.008) | (0.0037, 0.007, 0.041) | (0.0056, 0.008, 0.020) | (0.0056, 0.008, 0.012) |
| S15 | (0.0036, 0.004, 0.008) | (0.0037, 0.005, 0.008) | (0.0068, 0.009, 0.020) | (0.0056, 0.008, 0.012) |

**Table XVII.** Weighted normalized fuzzy decision matrix for solutions

weights of the barriers were changed. This indicates that the proposed integrated framework of the combination of fuzzy logic, AHP and TOPSIS is robust, systematic, effective, efficient and sensitive to barriers weights.

## 6. Conclusion

Coordination in HSCM is relatively low due to the presence of several barriers. Therefore, it is essential to overcome the barriers by providing solutions. It is difficult for practitioners to implement all solutions at the same time; therefore, ranking solutions is necessary for a stepwise implementation of these solutions. This study presents a more comprehensive and systematic framework for ranking solutions to enhance coordination by using a MCDM technique that combines fuzzy logic, AHP and TOPSIS. Humanists are often uncertain when it comes to assigning evaluation scores.

| SL. No | Solutions | $d+$ | $d-$ | Sum | $CC_i$ | Rank |
|---|---|---|---|---|---|---|
| S1 | Strategic tie up between actors | 0.3983001 | 22.711728 | 23.110028 | 0.9827651 | 7 |
| S2 | Commitment from the actors involved in HSC | 0.1980302 | 22.834473 | 23.032503 | 0.9914021 | 2 |
| S3 | Use of information technology | 0.4288646 | 22.667865 | 23.09673 | 0.9814318 | 10 |
| S4 | Regular meetings between actors of HSC | 0.4083011 | 22.7044 | 23.112701 | 0.9823343 | 8 |
| S5 | Build trustworthy environment within SC members | 0.4180704 | 22.697645 | 23.115716 | 0.981914 | 12 |
| S6 | Mutual learning of commercial and humanitarian organizations | 0.4082421 | 22.702681 | 23.110923 | 0.9823355 | 6 |
| S7 | Strengthen the cultural cohesions and cooperation's among the actors | 0.5357566 | 22.611729 | 23.147486 | 0.9768547 | 15 |
| S8 | Efficient training of workers | 0.3508378 | 22.731708 | 23.082545 | 0.9848007 | 9 |
| S9 | Establish a transparent work flow or open door policy | 0.1567104 | 22.854307 | 23.011017 | 0.9931898 | 3 |
| S10 | Need for performance measurement | 0.3014114 | 22.7571 | 23.058512 | 0.9869284 | 13 |
| S11 | Web based systems for easy access and low personal requirements | 0.4134957 | 22.68768 | 23.101176 | 0.9821007 | 14 |
| S12 | Easy to use information sharing and communication tools | 0.3685928 | 22.713398 | 23.081991 | 0.9840312 | 11 |
| S13 | Feedback mechanism to facilitate learning from prior experiences | 0.2199921 | 22.817506 | 23.037498 | 0.9904507 | 4 |
| S14 | Long-term focussed instead of short term | 0.1980302 | 22.834473 | 23.032503 | 0.9914021 | 1 |
| S15 | Policy for coordination | 0.2083828 | 22.82553 | 23.033913 | 0.9909532 | 5 |

**Table XVIII.** Closeness coefficient and final ranking of the solutions

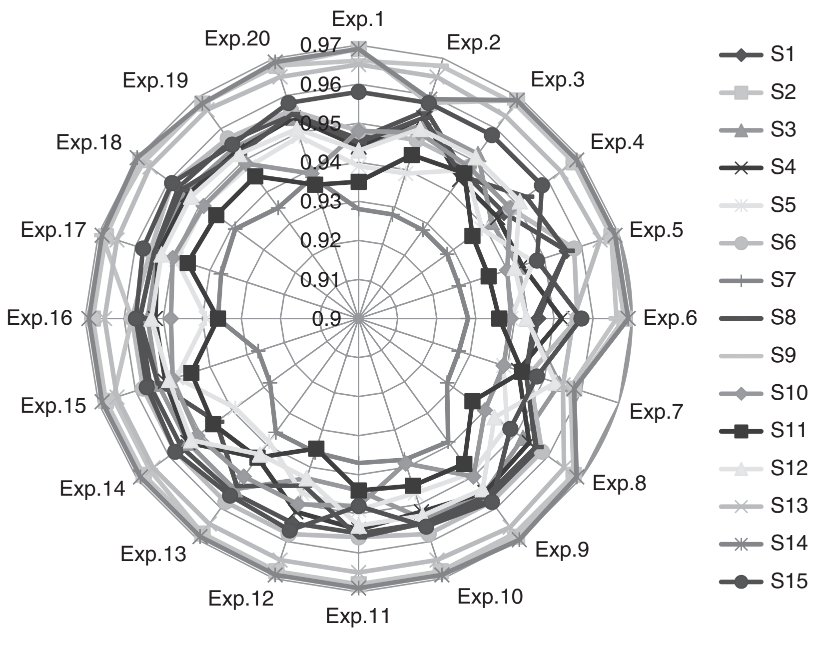



**Figure 5.** Result of sensitivity analysis ($CC_i$ scores)

Therefore, AHP and TOPSIS methods are performed in a fuzzy environment. Fuzzy AHP is used to estimate the weight of barriers while fuzzy TOPSIS is used to prioritize the solutions. The empirical case study of disaster that occurred in Uttarakhand (a Northern state in India) on June 14, 2013 demonstrates the applicability of the proposed framework.

In addition, a sensitivity analysis was performed to discuss and explain the results. The literature review and discussions with experts yielded 23 barriers and 15 solutions to overcome the barriers. These solutions were prioritized through an integrated framework of fuzzy logic, AHP and TOPSIS. The outcome of this study are twofold:

(1) identification of barriers to coordination in HSC; and

(2) identification and prioritization of the solutions to overcome the barriers to coordination.

The results indicate that developing a long-term relationship with commercial organizations, exchange programs and training for humanitarian logisticians in the commercial realm, and strategic tie-ups with organizations that have corporate social responsibility programs are important for enhancing the coordination in HSC. There is also a need to develop new coordination mechanisms, optimize the usage of scarce resources to reduce the suffering of the beneficiaries.

The results showed that long-term focussed planning instead of short-term focussed planning is the highest ranked solution to overcome the barriers to enhance coordination in HSCM in the Indian context. According to the results shown in the empirical case, the proposed method is robust, more systematic and practical, and gives a new and reliable approach to prioritize the solutions that overcome barriers to coordination in HSCM. Ranking solutions helps the various actors involved in relief operations make better choices that will enhance the efficiency and effectiveness of relief activities.

## 7. Limitations and future work

The study demonstrated that coordination is low in HSCM in India due to the presence of existing barriers. Solutions were also proposed and prioritized to enhance coordination. However, this study has several limitations that need to be acknowledged. One limitation is the interviewees and sectors from which they were drawn were restricted in number and the views expressed may not be typical. The second limitation is this study is limited to an Indian context and the views of the field managers toward the barriers to coordination is not considered. For further research, this study can be extended to other countries and the results of this study can be compared with other MCDM techniques like ANP, ELECTRE, VIKOR or PROMETHEE under a fuzzy environment.

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