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The Pre-positioned Warehouse Location Selection for International Humanitarian Relief Logistics

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ABSTRACT

This study aims to identify the most appropriate pre-positioned warehouse location for international humanitarian relief organisations. A two-step methodology is structured using fuzzy AHP and fuzzy TOPSIS to evaluate pre-positioned warehouse locations for humanitarian relief organisations. The empirical case study analysis of a humanitarian relief organisation is conducted to illustrate the use of the proposed framework for ranking alternative locations. This framework provides a more accurate, effective, and systematic decision support tool for stepwise implementation of warehouse location selection in humanitarian relief operations to increase efficiency. National stability is considered the most crucial factor for warehouse selection followed by host country cooperation. Location A was identified as the optimal warehouse location, with Locations D and E being relatively close. However, the organisation operates at Location A due to the national stability and government incentives such as land costs and customs exemption.

1. Introduction

Recent statistics indicate that natural disasters are occurring more frequently, resulting in significant societal losses. In 2016, natural disasters affected over 411 million people, causing more than 7,628 deaths in 102 countries (CRED, 2016). The economic damage alone was estimated to be $97 billion. Each year since 2005, over 300 disasters are estimated to strike our planet, killing around 75,000 people and impacting more than 170 million others.

As the rate of disasters rises, the importance of emergency response increases. Many global disasters have illustrated the importance of emergency relief logistics. When a major disaster strikes, the challenge is to deliver the appropriate emergency supplies in sufficient quantities exactly when and where they are needed (Klibi et al., 2013). The

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efficiency of logistics operations that account for 80% of relief operations (Van Wassenhove, 2006) is crucial to ensuring responsiveness when disaster occurs.

Several decision support systems and technologies have been developed for the preparation phase (Kovacs and Spens, 2007). One system is facility location, as decisions regarding stock pre-positioning in the relief chain are critical components of disaster preparedness and require long-term planning to achieve effective disaster response (Balcik and Beamon, 2008). Some relief organisations have recently implemented strategic pre-positioning to improve their capacities to deliver sufficient aid within a relatively short timeframe and with improved mobilisation (Balcik and Beamon, 2008). The basic purpose of establishing an emergency stockpile is to support life-saving operations in the first few days after a sudden-onset disaster through immediate delivery of necessary relief items (UNDHA, 1994). Speed of delivery in the relief chain is important when time pressure is often not simply a question of money but the difference between life and death (Van Wassenhove, 2006). Many relief organisations have recently established a pre-positioned strategic model to carry out extensive work to strengthen their logistical preparedness and capacity (Scott-Bowden, 2003).

This paper evaluates pre-positioned warehouses in the humanitarian sector. First, the concept of a pre-positioned warehouse is detailed, then the proposed methodology structure is given. A two-step fuzzy AHP and fuzzy TOPSIS methodology is structured here such that fuzzy TOPSIS uses the fuzzy AHP result weight as its input weights. Fuzzy AHP and fuzzy TOPSIS methods and calculations are given to clarify the methodology in detail. Then, a numerical example is presented to show the methodology's applicability and performance. A sensitivity analysis discusses and explains the methodology results.

2. Pre-Positioned Warehouse in Humanitarian Logistics

Once a disaster occurs, humanitarian organisations can acquire relief supplies from three main sources: local suppliers, global suppliers, and distribution centres (pre-positioned stocks) (Balcik and Beamon, 2008). During the disaster, logisticians first attempt to procure supplies from local sources, and if the relief organisation owns a centralised warehouse, the logistician then checks available supplies in those warehouses. The initial assessment is usually performed within the first 24 hours of a crisis to estimate the supplies required to meet the relief needs for the affected population (Thomas, 2007). A preliminary appeal for cash and supply donations is often made within 36 hours of the onset of the disaster. Anything that cannot be acquired locally or from a centralised warehouse is procured from global suppliers through a competitive bidding process (Beamon and Balcik, 2008). Aid agencies typically develop strong relationships with suppliers of items frequently needed in natural disasters and usually have long-term purchasing agreements with these firms (Kovacs and Spens, 2007).

One reason for pre-purchasing supplies is that they can be purchased at a reasonable price (Salisbury, 2007). Once a disaster occurs, demand for supplies increases dramatically, and suppliers will often raise their prices in response (Beamon and Balcik, 2008). Meanwhile, the distribution centres are located as close to the emergency as possible, depending on their strategic operations.

Even though there are more advantages in operating the pre-positioned facility, there are also several challenges to overcome to ensure the smooth flow of relief logistics. Firstly, some of the difficulties in creating an effective pre-positioning plan include uncertainty about whether natural disasters will occur and, if they do, where and to what magnitude (Rawls and Turnquist, 2010). Consequently, following a pre-prepositioning policy can be costly, and there are only a handful of relief organisations that can support the expense of operating international distribution centres (Balcik and Beamon, 2008; Salisbury, 2007). Non-governmental organisations (NGOs) are encouraged to focus on operational disaster relief activities rather than disaster preparedness because this enables them to reduce expenses and make their operations more effective over the long-term (Thomas, 2007). Most NGOs avoid a pre-positioning policy as it is both complicated and expensive (Balcik and Beamon, 2008). Another problem is that the total volume of demand satisfied from pre-positioned inventory is generally much less than the total volume of supplies sent to the disaster region over the entire relief horizon (Strash, 2004).

The overall goal for preparedness is to improve the rapid response facilities to allow timeliness of food aid in both sudden-onset and slow-onset emergency situations (Scott-Bowden, 2003). The objective of pre-positioning is to minimise the expected cost over all scenarios, resulting from the selection of the pre-positioned locations and facility sizes, commodity acquisition and stocking decisions, shipments of the supplies to the demand points, unmet demand penalties, and holding costs for unused material (Rawls and Turnquist, 2010). It is critical to improve disaster preparedness in supply chains because disruptions caused by external events can have significant financial and operational impacts when not properly prepared for (Hale and Moberg, 2005). One reason humanitarian relief organisations engage in preparatory activities to enhance their logistics capabilities is that post-disaster supply procurement brings challenges and risks in acquisition and delivery of adequate supplies, which tends to be time-consuming and expensive (Balcik and Beamon, 2008).

Although the theoretical research on facility location problems is extensive, applications of these problems have not received much attention in the domain of humanitarian relief (Balcik and Beamon, 2008). Balcik et al. (2010) discussed the role of pre-positioning warehouses in the aspect of disaster relief coordination practices. Balcik and Beamon (2008) studied the pre-positioning of facility location considering the response to the quick-onset disasters. The model considers pre-disaster and post-disaster budget restrictions but not network reliability. Campbell and Jones (2011) examined the decision of where to pre-position supplies in preparation for disaster and how much to stock at the warehouse considering the possibility of it being destroyed. Dekle et al. (2005) used a set-covering location model to locate disaster recovery centres in Florida. Gatigon et al. (2010) illustrated the implementation of a decentralised model at an international humanitarian organisation using the pre-positioning concept. Hale and Moberg (2005) proposed the use of a decision process with a set cover location model to help establish a network of secure site locations. They suggested the optimal location with a balance of operational effectiveness and cost-efficiency by identifying the minimum number and possible location of off-site storage facilities. Rawls and Turnquist (2010) provided an emergency response pre-positioning strategy for disaster threats considering uncertainty in demand for the stocked supplies, as well as uncertainty regarding transportation network availability post-disaster. Roh et al. (2015) used two case studies of humanitarian relief organisations at the macro- and micro-levels providing how such organisations consider various factors at each level when making location decisions. Ukkusuri and Yushimoto (2008) developed a model for pre-positioning of supplies and the problem of location routing incorporating the reliability of the ground transportation network.

Most of the existing literature regarding pre-positioned warehouse location problems mainly focuses on finding a potential optimal location with optimisation models rather than focusing on finding the important attributes for the location of the pre-positioned warehouse. Additionally, few studies have used multiple-attribute decision-making (MADM) methods, considering multiple tangible and intangible criteria as well as human judgement.

In this paper, pre-positioned warehouse location and the selection problem are evaluated. First, the evaluation criteria are determined by a modified Delphi method. Then, a two-level fuzzy AHP and fuzzy TOPSIS methodology is developed to decide the most appropriate pre-positioned warehouse location.

3. The Two-Step Fuzzy AHP and TOPSIS Methodology

Fuzzy multiple attribute decision-making (FMADM) methods have been developed owing to the imprecision in assessing the relative importance of attributes and the performance ratings of alternatives with respect to attributes. Imprecision may arise due to unquantifiable information, incomplete information, unobtainable information, and partial ignorance. Conventional MADM methods cannot effectively handle problems with such imprecise information. To resolve this difficulty, the fuzzy set theory, first introduced by Zadeh (1965), has been used and is adopted herein. The fuzzy linguistic approach is an approximate technique which represents qualitative aspects as linguistic values by means of linguistic variables; that is, variables whose values are not numbers but words or sentences. Fuzzy set theory attempts to select, prioritise, and rank a finite number of courses of action by evaluating a group of predetermined criteria. Solving this problem thus requires constructing an evaluation procedure to rate and rank, in order of preference, the set of alternatives.

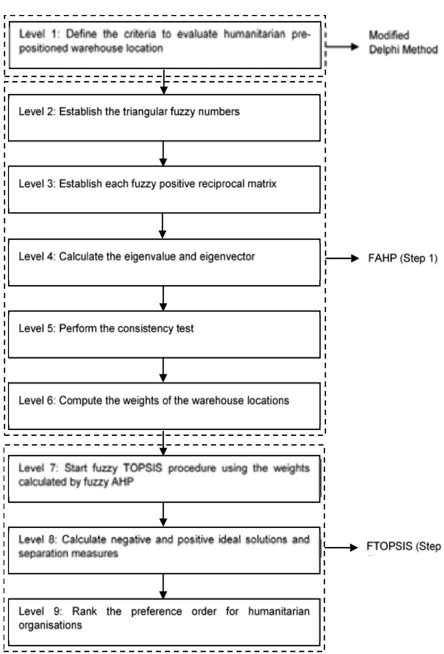

Fig. 1. The levels of the two-step methodology

This paper uses AHP and TOPSIS as a MADM technique together with fuzzy logic. The weights gained from fuzzy AHP calculations are considered and used in fuzzy TOPSIS calculations. It must be emphasised that the weights of fuzzy AHP are gained by a modified Delphi method. Then, fuzzy TOPSIS is applied for the evaluation problem, and the results show the preference order of the pre-positioned warehouse location. These methodology levels can be seen clearly in Figure 1. The levels of the methodology are detailed theoretically in following subsections.

3.1. *Modified Delphi Method*

The Delphi method accumulates and analyses the results of anonymous experts who communicate in written discussion and feedback formats on specific topics. They share knowledge, skills, expertise, and opinions until a mutual consensus is achieved (Chang et al., 2008; Hartman, 1981). The Delphi method consists of five procedures: (1) select the anonymous experts; (2) conduct the first round of a questionnaire survey; (3) conduct the second round of the survey; (4) conduct the third round of the survey; and (5) integrate expert opinions and reach a consensus. Steps (3) and (4) are normally repeated until a consensus is reached (Chang et al., 2008).

The decision-making group should not be too large (i.e., between five and fifty people) (Robbins, 1994). Murry and Hammons suggested (1995) that the modified Delphi method summarises expert opinions on a range from 10 to 30 (Chang et al., 2008). Therefore, in this study, eleven experts participated in the modified Delphi method-based decision group.

3.2. *Fuzzy Analytic Hierarchy Process Model*

The Analytic Hierarchy Process (AHP), developed by Saaty (1980), is a powerful method to solve complex decision problems by obtaining the relative weights among the factors and the total values of each and the total values of each alternative based on these weights (Torfi et al., 2010). This process makes it possible to incorporate judgements on intangible qualitative criteria alongside tangible quantitative criteria (Badri, 2001).

Numerous papers have adopted AHP method for the maritime studies. However, the conventional AHP model has some limitations, according to Yang & Chen (2004), who pointed out that the AHP method is mainly used in nearly crisp-information decision applications. This method creates deals with a very unbalanced scale of judgement; it does not consider the uncertainty associated with mapping human judgement to a number by natural language. The ranking of the AHP method is rather imprecise, and subjective judgement by perception, evaluation, improvement, and selection based on preference of decision-makers greatly influences the results.

To overcome these problems, several researchers integrate fuzzy theory with AHP to improve certainty. The fuzzy AHP method offers such benefits as the ability to capture uncertain imprecise judgement of experts by handling linguistic variables. There are many fuzzy AHP methods proposed by various authors (Buckley, 1985; Chang, 1996; Cheng, 1997; Deng, 1999; Gumus, 2009; Leung and Gao, 2000; Mikhailov, 2004). These methods are systematic approaches to the alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis. Buckley (1985) used the evolutionary algorithm to calculate the weights with the trapezoidal fuzzy numbers. The fuzzy AHP was based on the fuzzy interval arithmetic with triangular fuzzy numbers and confidence index α with an interval mean approach to determine the weights for evaluating elements.

3.2.1 *Building the Evaluation Hierarchy Systems for Pre-Positioned Warehouse Location Sites for International Humanitarian Organisations*

This research tries to evaluate the problem of pre-positioning locations of humanitarian facilities in the relief decision-making process. After reviewing the related literature and interviewing eleven decision-makers in international humanitarian organisations, the building of the evaluation hierarchy systems was set. Based on the evaluation criteria, this study identified five warehouse locations for evaluating pre-positioned warehouse locations.

3.2.2 *Determining the evaluation dimension weights*

This research employs fuzzy AHP to "fuzzify" the hierarchical analysis by allowing fuzzy numbers for the pairwise comparisons and find the fuzzy preference weights. In this section, concepts for fuzzy hierarchical evaluation will be briefly reviewed, and the computational process of fuzzy AHP will be introduced in detail.

Establishing fuzzy numbers

Fuzzy sets are those whose elements have degrees of membership. Zadeh (1965) introduced an extension of the classical notion of the set. In classical theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition – an element either belongs or does not belong to the set (Liou et al., 2007; Wu and Lee, 2007). The mathematics concept was borrowed from Hsieh et al. (2004) and Liou et al. (2007).

A fuzzy number $\tilde{A}$ on R is to be a TFN if its membership function $\mu_{\tilde{a}}(x): R \rightarrow [0, 1]$ is equal to following Eq. (1):

$$\mu_{\tilde{a}}(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

From Eq. (1), l and u refer to the lower and upper bounds of the fuzzy number $\tilde{A}$, respectively, and m is the model value for $\tilde{A}$ (as Figure 2). The *TFN* can be denoted by $\tilde{A} = (l, m, u)$. The operational laws of *TFN* $\tilde{A}_1 = (l_1, m_1, u_1)$ and *TFN* $\tilde{A}_2 = (l_2, m_2, u_2)$ can be expressed as the following Eqs. (2) – (6).

Addition of the fuzzy number ⊕

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

Multiplication of the fuzzy number ⊗

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \text{ for } l_1, l_2 > 0;\ m_1, m_2 > 0;\ u_1, u_2 > 0 \quad (3)$$

Subtraction of the fuzzy number Θ

$$\tilde{A}_1 \Theta \tilde{A}_2 = (l_1, m_1, u_1) \Theta (l_2, m_2, u_2) = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \quad (4)$$

Multiplication of the fuzzy number ∅

$$\tilde{A}_1 \emptyset \tilde{A}_2 = (l_1, m_1, u_1) \emptyset (l_2, m_2, u_2) = (l_1 / l_2, m_1 / m_2, u_1 / u_2) \text{ for } l_1, l_2 > 0;\ m_1, m_2 > 0;\ u_1, u_2 > 0 \quad (5)$$

Reciprocal of the fuzzy number

$$\tilde{A}^{-1} = (l_1, m_1, u_1)^{-1} = (1/u_1, 1/m_1, 1/l_1) \text{ for } l_1, l_2 > 0;\ m_1, m_2 > 0;\ u_1, u_2 > 0 \quad (6)$$

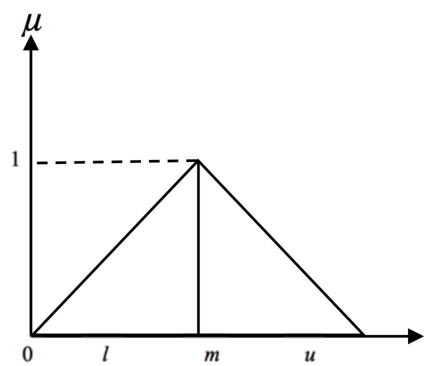

Fig. 2. The membership functions of the triangular fuzzy number

Determining the linguistic variables

The concept of linguistic variables is very useful in dealing with situations too complex or ill-defined to be reasonably described in conventional quantitative expressions (Zadeh, 1975). A linguistic variable is a variable whose values are words or sentences in a natural or artificial language. The linguistic comparison terms and their equivalent fuzzy numbers considered in this paper are shown in Table 1, defined by Gumus (2009).

Table 1
Fuzzy comparison measures

Fuzzy number	Linguistic	Scale of fuzzy number
9	Perfect	(8, 9, 10)
8	Absolute	(7, 8, 9)
7	Very good	(6, 7, 8)
6	Fairly good	(5, 6, 7)
5	Good	(4, 5, 6)
4	Preferable	(3, 4, 5)
3	Not bad	(2, 3, 4)
2	Weak advantage	(1, 2, 3)
1	Equal	(1, 1, 1)

3.2.3 *Fuzzy AHP*

The following section will briefly introduce the procedure of fuzzy AHP.

Step 1: Construct pairwise comparison matrices among all the elements/criteria in the dimensions of the hierarchy system. Assign linguistic terms to the pairwise comparisons by asking which is the more important of each two dimensions, as following matrix $\tilde{\mathbf{A}}$ as shown in Eq. (7).

$$\tilde{\mathbf{A}} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \ddots & \vdots & \vdots \\ 1/\tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} \quad (7)$$

Step 2: Examine the consistency of the fuzzy pairwise comparison matrices. According to the research of Buckley (1985), it proves that if $\mathbf{A} = [\alpha_{ij}]$ is a positive reciprocal matrix then $\tilde{\mathbf{A}} = [\tilde{\alpha}_{ij}]$ is a fuzzy positive reciprocal matrix. That is, if the result of the comparisons of $\mathbf{A} = [\alpha_{ij}]$ is consistent, then it can imply that the result of the comparisons of $\tilde{\mathbf{A}} = [\tilde{\alpha}_{ij}]$ is also consistent. Therefore, this research employs this method to validate the questionnaire.

Step 3: Compute the fuzzy geometric mean for each criterion. The geometric technique is used to calculate the geometric mean ($\tilde{r}_i$) of the fuzzy comparison values of criterion *I* to each criterion, as shown in Eq. (8), where $\tilde{\alpha}_{in}$ is a fuzzy value of the pair-wise comparison of criterion *i* to criterion *n* (Buckley, 1995)

$$\tilde{r}_i = [\tilde{\alpha}_{i1} \otimes \dots \otimes \tilde{\alpha}_{in}]^{1/n} \quad (8)$$

Step 4: Compute the fuzzy weights by normalisation. The fuzzy weight of the *i*th criterion ($\bar{\mathbf{w}}_i$), can be derived as Eq. (9), where $\bar{\mathbf{w}}_i$ is denoted as $\bar{\mathbf{w}}_i = (L_{wi}, M_{wi}, U_{wi})$ by a TFN and L_{wi}, M_{wi}, and U_{wi} represent the lower, middle, and upper values of the fuzzy weight of the *i*th criterion

$$\bar{\mathbf{w}}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \dots \oplus \tilde{r}_n)^{-1} \quad (9)$$

There are numerous studies that apply fuzzy AHP.

3.3. *The Fuzzy TOPSIS Method*

In this study, we propose this method to evaluate the warehouse location for international humanitarian organisations. TOPSIS was developed by Hwang and Yoon (1981), based on the concept that chosen/improved alternatives should be the shortest distance from the positive-ideal solution (PIS) and the farthest from the negative-ideal solution (NIS) for solving a MCDM problem. Thus, the best alternative should not only be the shortest distance away from the positive ideal solution but should also be the longest distance away from the negative-ideal solution. In short, the ideal solution is composed of all the criteria with the best values attainable, whereas the negative-ideal solution is made up of all the criteria with the worst values attainable. It is often difficult for a decision-maker to assign a precise evaluation rating to an alternative for the attributes under consideration. The merit of using a fuzzy approach is to assign the relative importance of attributes using fuzzy numbers instead of precise numbers for suiting the real world fuzzy environment. This section extends the TOPSIS to the fuzzy environment (Kuo et al., 2007). This method is particularly suitable for solving the group decision-making problem under a fuzzy environment. The mathematics concept was borrowed from Kuo et al. (2007).

Step 1: Determine the weighting of evaluation criteria.
This research employs fuzzy AHP to find the fuzzy preference weights.

Step 2: Construct the fuzzy performance/decision matrix and choose the appropriate linguistic variables for the alternatives with respect to criteria.

$$\tilde{\mathbf{D}} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_1 & \dots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \end{array} \quad (10)$$

$i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n$

$\tilde{x}_{ij} = \frac{1}{K}(\tilde{x}^1_{ij} \oplus \dots \oplus \tilde{x}^k_{ij} \oplus \dots \oplus \tilde{x}^k_{ij})$

Where $\tilde{x}^k{}_{ij}$ is the performance rating of alternative A_i with respect to criterion C_j evaluated by *k*th expert, and $\tilde{x}^k{}_{ij} = (l^k_{ij}, m^k_{ij}, u^k_{ij})$.

Step 3: Normalise the fuzzy-decision matrix.
The normalised fuzzy-decision denoted by $\tilde{\mathbf{R}}$ is shown as the following formula:

$$\tilde{\mathbf{R}} = [\tilde{r}_{ij}]_{m \times n} \quad i = 1, 2, \dots, m; \; j = 1, 2, \dots, n \quad (11)$$

Then, the normalisation process can be performed by the following formula:

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{U_j^+}, \frac{l_{ij}}{U_j^+}, \frac{l_{ij}}{U_j^+}\right), \; U_j^+ = \max_i \{u_{ij} | i = 1, 2, \dots, n\}$$

Or we can set the best aspired level U_j^+ and $j = 1, 2, \dots, n$ is equal one; otherwise, the worst is zero.
The normalised $\tilde{r}_{ij}$ is still triangular fuzzy numbers. For trapezoidal fuzzy numbers, the normalisation process can be conducted in the same way. The weighted fuzzy normalised decision matrix is shown as the following matrix $\tilde{\mathbf{V}}$:

$$\tilde{\mathbf{V}} = [\tilde{v}_{ij}]_{n \times n}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \quad (12)$$

where $\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j$.

Step 4: Determine the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNPIS).
According to the weighted normalised fuzzy-decision matrix, the elements $\tilde{v}_{ij}$ are normalised positive *TFN* and their ranges belong to the closed interval [0,1]. Then, we can define the FPIS A^+ (aspiration levels) and FNIS A^- (the worst levels) as following formula:

$$A^+ = (\tilde{v}_1^*, \dots, \tilde{v}_i^*, \dots, \tilde{v}_n^*) \quad (13)$$
$$A^- = (\tilde{v}_1^-, \dots, \tilde{v}_i^-, \dots, \tilde{v}_n^-) \quad (14)$$

Where $\tilde{v}_i^* = (1, 1, 1) \otimes (lw_i, mw_i, uw_i)$ and $\tilde{v}_i^- = (0, 0, 0)$, $i = 1, 2, , n$.

Step 5: Calculate the distance of each alternative from FPIS and FNIS.
The distances ($\tilde{d}_i^+$and $\tilde{d}_i^-$) of each alternative from A^+ and A^- can be currently calculated by the area compensation method.

$$\tilde{D}_j^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_i^*), \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \quad (15)$$
$$\tilde{D}_j^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_i^-), \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \quad (16)$$

Step 6: Obtain the closeness coefficients (relative gaps-degree) and improve alternatives for achieving aspiration levels in each criterion.

$$\widetilde{CC}_j = \frac{\tilde{d}_j^-}{\tilde{d}_j^- + \tilde{d}_j^+} = 1 - \frac{\tilde{d}_i^+}{\tilde{d}_j^- + \tilde{d}_j^+}, \quad j = 1, 2, \dots, \text{m} \quad (17)$$

4. An Empirical Example for Humanitarian Warehouse Location

The problem is the evaluation of pre-positioned warehouses and the selection of the most appropriate one. For this reason, five major criteria and 25 sub-criteria are determined to evaluate five alternative locations using a modified Delphi method. Secondly, a two-step fuzzy AHP and fuzzy TOPSIS methodology are proposed to realise the evaluation. The fuzzy AHP was used to obtain the fuzzy weights of the criteria and these calculated weights are used as fuzzy TOPSIS inputs. Then, after fuzzy TOPSIS calculations, alternatives are evaluated and the most appropriate one is selected. At the end of this section, the methodology structure and results are analysed in detail by sensitivity analysis.

4.1. *Modified Delphi Method*

Here, five alternative warehouse locations are evaluated as A, B, C, D, and E. The modified Delphi method is used as explained in Section 3.1 and a group of eleven experts determined five major criteria and 25 sub-criteria for evaluation. The hierarchical structure of this research decision problem is shown in Figure 3. The 25 sub-criteria are grouped into five major criteria of warehouse location selection, 'Location (C1): C11 – C17', 'National Stability (C2): C21 – C22', 'Cost (C3): C31 – C35', 'Cooperation (C4): C41 – C46', and 'Logistics (C5): C51 – C55'.

A=

	C1	C2	C3	C4	C5
C1	1	(1.22,1.63,2.08)	(0.87,1.05,1.24)	(2.37,2.91,3.46)	(2.21,2.66,3.05)
C2	(0.48,0.62,0.82)	1	(0.93,1.22,1.48)	(1.13,1.42,1.71)	(0.83,0.93,1.06)
C3	(0.81,0.95,1.15)	(0.68,0.82,1.07)	1	(1.18,1.62,2.04)	(0.77,0.97,1.19)
C4	(0.29,0.34,0.42)	(0.59,0.71,0.88)	(0.49,0.62,0.85)	1	(0.54,0.62,0.74)
C5	(0.33,0.38,0.45)	(0.94,1.07,1.21)	(0.84,1.03,1.30)	(1.35,1.61,1.86)	1

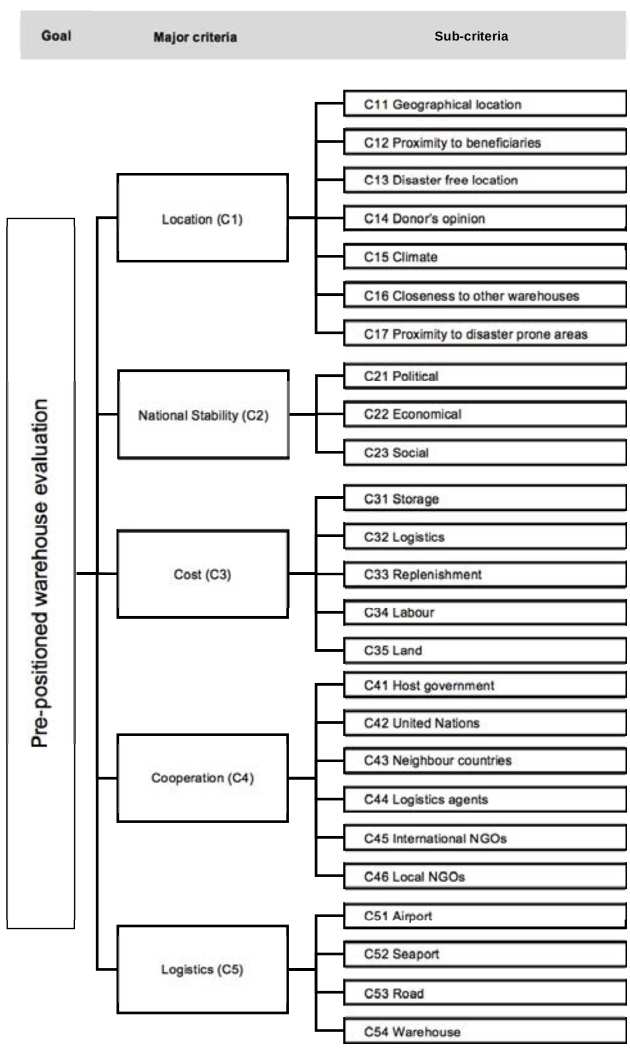

Fig. 3. Hierarchical framework for pre-positioned warehouse evaluation criteria for humanitarian relief

4.2. *Weights of Evaluation Criteria*

Fuzzy AHP method is adopted to evaluate the weights of different criteria for the warehouse location selection. Following the construction of fuzzy AHP model, it is extremely important that experts fill the judgement matrix.

The following section demonstrates the computational procedure of the criteria weights.

(1) The pairwise comparison matrices of dimensions will be obtained according to the committee of eleven experts regarding the relative importance of criteria. Fuzzy numbers defined in Table 1 are applied.
(2) Computing the elements of synthetic pairwise comparison matrix by using the geometric mean method suggested by Buckley (1985), that is:

$\tilde{a}_{ij} = (\tilde{a}_{ij}^{1} \otimes \tilde{a}_{ij}^{2} \otimes \ldots \otimes \tilde{a}_{ij}^{10})$, for $\tilde{a}_{12}$ as the example:

$$\tilde{a}_{12} = (6, 7, 8) \otimes (2, 3, 4) \otimes \cdots \otimes (1, 2, 3)^{1/11}$$
$$= ((6 \times 2 \times \cdots \times 1)^{1/11}, (7 \times 3 \times \cdots \times 2)^{1/11}, (8 \times 4 \times \cdots \times 3)^{1/11}) = (1.22, 1.63, 2.08)$$

The other matrix elements can be obtained by the same computational procedure, therefore, the synthetic major criteria pairwise comparison matrices of the eleven experts will be constructed as follows in matrix ***A***:

(3) To calculate the fuzzy weights of criteria, the computation procedures are displayed as the following parts:

$$\tilde{r}_1 = (\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \tilde{a}_{13} \otimes \tilde{a}_{14} \otimes \tilde{a}_{15})^{1/5}$$
$$= ((1 \times 1.22 \times \cdots \times 2.21)^{1/5}, (1 \times 1.63 \times \cdots \times 2.66)^{1/5}, (1 \times 2.08 \times \cdots \times 3.05)^{1/5})$$
$$= (1.4110, 1.6768, 1.9332)$$

Similarly, the remaining $\tilde{r}_i$ can be obtained as follows:

$\tilde{r}_2 = (0.8406, 0.9980, 1.1702)$
$\tilde{r}_3 = (0.8693, 1.0407, 1.2459)$
$\tilde{r}_4 = (1.8627, 0.6222, 0.7480)$
$\tilde{r}_5 = (0.8103, 0.9229, 1.0576)$

For the weight of each criterion, they can be done as follows:

$$\tilde{w}_1 = \tilde{r}_1 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5)^{-1}$$
$$= ((1.4110, 1.6768, 1.9332) \otimes (1/1.9332 + \cdots + 1.0576), (1/1.6768 + \cdots + 0.9229), (1/1.4110 + \cdots + 0.8103))$$
$$= (0.229, 0.319, 0.334)$$

The remaining $\tilde{w}_i$, can be calculated as below:

$\tilde{w}_2 = (0.137, 0.160, 0.202)$
$\tilde{w}_3 = (0.141, 0.243, 0.215)$
$\tilde{w}_4 = (0.303, 0.720, 0.129)$
$\tilde{w}_5 = (0.132, 0.524, 0.183)$

(4) To apply the centre of area (COA) method to compute the *best non-fuzzy performance (BNP)* value of the fuzzy weights of each criterion, take the *BNP* value of the weight of C_1 (Location). The calculation process is as follows:

$$BNP_{w1} = [(U_{w1} - L_{w1}) + (M_{w1} - L_{w1})]/3 + L_{w1}$$
$$= [(0.2276 - 0.1103) + (0.1578 - 0.1103)]/3 + 0.1103$$
$$= 0.1652$$

Then, the weights for the remaining major and sub-criteria can be found in Table 2. The result shows that the critical order of the five major criteria for warehouse location evaluation is 'national stability (C2): 0.2868', cooperation (C4): 0.2089', 'cost (C3): 0.1914', 'location (C1): 0.1587', and 'logistics (C5): 0.1541'.

Table 2
Fuzzy weights of pre-positioned warehouse location evaluation by FAHP

Criteria (Major and sub)	Local weights	Overall weights	BNP[a]	STD_ BNP[b]	Rank
(C1) Location	**(0.1103, 0.1578, 0.2276)**		**0.1652**	**0.1587**	**4**
(C11) Geographical location	(0.1058, 0.1577, 0.2270)	(0.0117, 0.0249, 0.0157)	0.0294	0.0255	20
(C12) Proximity to beneficiaries	(0.0870, 0.1261, 0.1834)	(0.0096, 0.0199, 0.0417)	0.0237	0.0206	22
(C13) Disaster free location	(0.0762, 0.1125, 0.1684)	(0.0084, 0.0178, 0.0383)	0.0215	0.0187	24
(C14) Donor's opinion	(0.0862, 0.1249, 0.1839)	(0.0095, 0.0197, 0.0418)	0.0237	0.0206	23
(C15) Climate	(0.1554, 0.2291, 0.3306)	(0.0171, 0.0361, 0.0752)	0.0428	0.0372	11
(C16) Closeness to other warehouses	(0.1136, 0.1620, 0.2354)	(0.0125, 0.0256, 0.0536)	0.0306	0.0265	19
(C17) Proximity to disaster prone area	(0.0624, 0.0876, 0.1277)	(0.0069, 0.0138, 0.0291)	0.0166	0.0144	25
(C2) National stability	**(0.1978, 0.2886, 0.4093)**		**0.2985**	**0.2868**	**1**
(C21) Political	(0.1965, 0.2370, 0.2821)	(0.0389, 0.0684, 0.1154)	0.0742	0.0645	3
(C22) Economical	(0.2721, 0.3258, 0.3966)	(0.0538, 0.0940, 0.1623)	0.1034	0.0898	2
(C23) Social	(0.3580, 0.4371, 0.5312)	(0.0708, 0.1262, 0.2174)	0.1381	0.1199	1
(C3) Cost	**(0.1360, 0.1906, 0.2711)**		**0.1992**	**0.1914**	**3**
(C31) Storage	(0.1197, 0.1617, 0.2144)	(0.0163, 0.0308, 0.0581)	0.0351	0.0305	16
(C32) Logistics	(0.1152, 0.1539, 0.2100)	(0.0157, 0.0293, 0.0569)	0.0340	0.0295	18
(C33) Replenishment	(0.1226, 0.1650, 0.2325)	(0.0167, 0.0315, 0.0630)	0.0371	0.0322	15
(C34) Labour	(0.1620, 0.2367, 0.3299)	(0.0220, 0.0451, 0.0895)	0.0522	0.0453	6
(C35) Land	(0.2022, 0.2827, 0.3989)	(0.0275, 0.0539, 0.1081)	0.0632	0.0549	4
(C4) Cooperation	**(0.1508, 0.2095, 0.2919)**		**0.2174**	**0.2089**	**2**
(C41) Host government	(0.1306, 0.2129, 0.3213)	(0.0197, 0.0446, 0.0938)	0.0527	0.0458	5
(C42) United Nations	(0.0710, 0.1050, 0.1581)	(0.0107, 0.0220, 0.0461)	0.0263	0.0228	21
(C43) Neighbour countries	(0.1400, 0.2090, 0.3071)	(0.0211, 0.0438, 0.0896)	0.0515	0.0447	7
(C44) Logistics agents	(0.0936, 0.1355, 0.2050)	(0.0141, 0.0284, 0.0598)	0.0341	0.0296	17
(C45) International NGOs	(0.1222, 0.1802, 0.2695)	(0.0184, 0.0378, 0.0787)	0.0450	0.0390	10
(C46) Local NGOs	(0.1076, 0.1574, 0.2429)	(0.0162, 0.0330, 0.0709)	0.0400	0.0348	13
(C5) Logistics	**(0.1110, 0.1535, 0.2167)**		**0.1604**	**0.1541**	**5**
(C51) Airport	(0.1670, 0.2266, 0.3027)	(0.0185, 0.0348, 0.0656)	0.0396	0.0344	14
(C52) Seaport	(0.1738, 0.2327, 0.3158)	(0.0193, 0.0357, 0.0684)	0.0412	0.0357	12
(C53) Road	(0.2058, 0.2790, 0.3832)	(0.0228, 0.0428, 0.0831)	0.0496	0.0431	8
(C54) Warehouse	(0.1918, 0.2618, 0.3528)	(0.0213, 0.0402, 0.0765)	0.0460	0.0399	9

[a] BNP (Best non-fuzzy performance) = $[(U - L) + (M - L)]/3 + L$.
[b] STD_BNP: standardised BNP

The five most important evaluations of sub-criteria are 'social (C23): 0.1199', 'economical (C22): 0.0898', 'political (C21): 0.0645', 'land (C35): 0.0549', and 'host government (C41): 0.0458'. The least important evaluation sub-criterion is 'proximity to disaster prone area (C17): 0.0144'.

4.3. *Evaluation of the warehouse location and determination of the final rank*

At this stage of the decision process, the team of experts was asked to establish the decision matrix by comparing alternatives under each criterion separately. The fuzzy evaluation matrix established by the evaluation of warehouse locations by linguistic variables in Table 3 included 'very low', 'low', 'medium', 'high', and 'very high' to express their opinions about the rating of locations regarding each major and sub-criterion in Table 4.

Table 3
Linguistic values and fuzzy numbers

Linguistic values	Fuzzy numbers
Very low (VL)	(0, 1, 3)
Low (L)	(1, 3, 5)
Medium (M)	(3, 5, 7)
High (H)	(5, 7, 9)
Very high (VH)	(7, 9, 10)

Table 4
Subjective cognition results of evaluators towards the five levels of linguistics variables

	A	B	C	D	E
C11	(6.3, 8.3, 9.7)	(5.0, 7.0, 8.7)	(1.0, 3.0, 5.0)	(3.0, 5.0, 7.0)	(4.0, 6.0, 7.5)
C12	(4.3, 6.3, 8.3)	(2.3, 4.3, 6.3)	(5.0, 7.0, 9.0)	(4.0, 6.0, 8.0)	(6.0, 8.0, 9.5)
C13	(7.0, 9.0, 10.0)	(5.7, 7.7, 9.0)	(3.0, 5.0, 7.0)	(4.0, 6.0, 8.0)	(5.0, 7.0, 8.5)
C14	(5.0, 7.0, 9.0)	(5.7, 7.7, 9.3)	(3.0, 5.0, 7.0)	(4.0, 6.0, 8.0)	(6.0, 8.0, 9.5)
C15	(3.7, 5.7, 7.7)	(4.7, 6.3, 7.7)	(5.0, 7.0, 9.0)	(4.0, 6.0, 8.0)	(6.0, 8.0, 9.5)
C16	(3.0, 5.0, 7.0)	(2.0, 3.7, 5.7)	(5.0, 7.0, 9.0)	(4.0, 6.0, 8.0)	(5.0, 7.0, 9.0)
C17	(3.7, 5.7, 7.7)	(3.0, 5.0, 7.0)	(5.0, 7.0, 9.0)	(4.0, 6.0, 8.0)	(6.0, 8.0, 9.5)
C21	(5.7, 7.7, 9.3)	(6.3, 8.3, 9.7)	(1.0, 3.0, 5.0)	(2.0, 4.0, 6.0)	(3.0, 5.0, 7.0)
C22	(4.3, 6.3, 8.3)	(5.0, 7.0, 9.0)	(3.0, 5.0, 7.0)	(2.0, 4.0, 6.0)	(3.0, 5.0, 7.0)
C23	(6.3, 8.3, 9.7)	(5.7, 7.7, 9.3)	(1.0, 3.0, 5.0)	(2.0, 4.0, 6.0)	(3.0, 5.0, 7.0)
C31	(6.3, 8.3, 9.7)	(2.3, 4.3, 6.3)	(5.0, 7.0, 9.0)	(4.0, 6.0, 8.0)	(6.0, 8.0, 9.5)
C32	(4.3, 6.3, 8.3)	(3.7, 5.7, 7.7)	(5.0, 7.0, 9.0)	(4.0, 6.0, 8.0)	(4.0, 6.0, 8.0)
C33	(5.7, 7.7, 9.3)	(3.7, 5.7, 7.7)	(3.0, 5.0, 7.0)	(4.0, 6.0, 8.0)	(4.0, 6.0, 8.0)
C34	(3.7, 5.7, 7.7)	(0.0, 1.0, 3.0)	(7.0, 9.0, 10.0)	(6.0, 8.0, 9.5)	(7.0, 9.0, 10.0)
C35	(6.3, 8.3, 9.7)	(1.0, 2.3, 4.3)	(5.0, 7.0, 9.0)	(3.0, 5.0, 7.0)	(7.0, 9.0, 10.0)
C41	(5.0, 7.0, 9.0)	(5.0, 7.0, 9.0)	(3.0, 5.0, 7.0)	(6.3, 8.3, 9.7)	(3.0, 5.0, 7.0)
C42	(5.7, 7.7, 9.3)	(6.3, 8.3, 9.7)	(3.0, 5.0, 7.0)	(3.7, 5.7, 7.7)	(3.0, 5.0, 7.0)
C43	(3.7, 5.7, 7.7)	(5.0, 7.0, 9.0)	(3.0, 5.0, 7.0)	(3.0, 5.0, 7.0)	(3.0, 5.0, 7.0)
C44	(6.0, 8.0, 9.5)	(5.0, 7.0, 9.0)	(3.0, 5.0, 7.0)	(5.0, 7.0, 9.0)	(3.0, 5.0, 7.0)
C45	(5.0, 7.0, 8.7)	(4.3, 6.3, 8.3)	(3.0, 5.0, 7.0)	(3.7, 5.7, 7.7)	(3.0, 5.0, 7.0)
C46	(5.0, 7.0, 8.7)	(3.7, 5.7, 7.7)	(3.0, 5.0, 7.0)	(3.7, 5.7, 7.7)	(3.0, 5.0, 7.0)
C51	(7.0, 9.0, 10.0)	(6.3, 8.3, 9.7)	(3.0, 5.0, 7.0)	(4.0, 6.0, 8.0)	(3.0, 5.0, 7.0)
C52	(7.0, 9.0, 10.0)	(5.7, 7.7, 9.0)	(3.0, 5.0, 7.0)	(4.0, 6.0, 8.0)	(5.0, 7.0, 9.0)
C53	(7.0, 9.0, 10.0)	(7.0, 9.0, 10.0)	(3.0, 5.0, 7.0)	(5.0, 7.0, 9.0)	(4.0, 6.0, 8.0)
C54	(6.3, 8.3, 9.7)	(5.7, 7.7, 9.0)	(1.0, 3.0, 5.0)	(3.0, 5.0, 7.0)	(3.0, 5.0, 7.0)

Table 5
Normalised fuzzy-decision matrix

	A	B	C	D	E	Weight
C11	(0.664, 0.607, 0.559)	(0.524, 0.510, 0.501)	(0.105, 0.219, 0.289)	(0.314, 0.364, 0.405)	(0.419, 0.437, 0.434)	0.0255
C12	(0.431, 0.439, 0.499)	(0.232, 0.301, 0.341)	(0.497, 0.485, 0.485)	(0.398, 0.416, 0.431)	(0.596, 0.555, 0.512)	0.0206
C13	(0.611, 0.569, 0.523)	(0.495, 0.485, 0.470)	(0.262, 0.316, 0.366)	(0.349, 0.380, 0.418)	(0.437, 0.443, 0.444)	0.0187
C14	(0.460, 0.459, 0.467)	(0.521, 0.502, 0.484)	(0.276, 0.328, 0.363)	(0.368, 0.393, 0.415)	(0.552, 0.524, 0.493)	0.0206
C15	(0.346, 0.381, 0.408)	(0.441, 0.426, 0.408)	(0.472, 0.471, 0.479)	(0.378, 0.403, 0.426)	(0.566, 0.538, 0.506)	0.0372
C16	(0.338, 0.381, 0.399)	(0.225, 0.279, 0.323)	(0.563, 0.533, 0.514)	(0.450, 0.457, 0.457)	(0.563, 0.533, 0.514)	0.0265
C17	(0.368, 0.395, 0.414)	(0.301, 0.348, 0.378)	(0.501, 0.488, 0.486)	(0.401, 0.418, 0.432)	(0.602, 0.557, 0.513)	0.0144
C21	(0.610, 0.574, 0.548)	(0.682, 0.624, 0.567)	(0.108, 0.225, 0.293)	(0.215, 0.300, 0.352)	(0.323, 0.375, 0.411)	0.0645
C22	(0.534, 0.509, 0.494)	(0.616, 0.562, 0.534)	(0.370, 0.401, 0.415)	(0.247, 0.321, 0.356)	(0.370, 0.401, 0.415)	0.0898
C23	(0.682, 0.624, 0.567)	(0.610, 0.574, 0.548)	(0.108, 0.225, 0.293)	(0.215, 0.300, 0.352)	(0.323, 0.375, 0.411)	0.1199
C31	(0.572, 0.541, 0.503)	(0.211, 0.281, 0.330)	(0.452, 0.454, 0.330)	(0.361, 0.390, 0.417)	(0.542, 0.519, 0.495)	0.0305
C32	(0.459, 0.456, 0.454)	(0.388, 0.408, 0.417)	(0.529, 0.504, 0.490)	(0.423, 0.432, 0.436)	(0.423, 0.432, 0.436)	0.0295
C33	(0.609, 0.559, 0.519)	(0.394, 0.413, 0.427)	(0.322, 0.365, 0.390)	(0.430, 0.438, 0.445)	(0.430, 0.438, 0.445)	0.0322
C34	(0.302, 0.352, 0.405)	(0.000, 0.062, 0.159)	(0.576, 0.559, 0.528)	(0.494, 0.497, 0.502)	(0.576, 0.559, 0.528)	0.0453
C35	(0.568, 0.550, 0.523)	(0.090, 0.154, 0.234)	(0.449, 0.462, 0.487)	(0.269, 0.330, 0.378)	(0.628, 0.594, 0.541)	0.0549
C41	(0.481, 0.475, 0.479)	(0.481, 0.475, 0.479)	(0.289, 0.339, 0.372)	(0.609, 0.565, 0.514)	(0.289, 0.339, 0.372)	0.0458
C42	(0.557, 0.529, 0.508)	(0.622, 0.575, 0.526)	(0.295, 0.345, 0.381)	(0.360, 0.391, 0.417)	(0.295, 0.345, 0.381)	0.0228
C43	(0.453, 0.454, 0.453)	(0.618, 0.560, 0.531)	(0.371, 0.400, 0.413)	(0.371, 0.400, 0.413)	(0.371, 0.400, 0.413)	0.0447
C44	(0.588, 0.549, 0.508)	(0.490, 0.481, 0.481)	(0.294, 0.343, 0.374)	(0.490, 0.481, 0.481)	(0.294, 0.343, 0.374)	0.0296
C45	(0.576, 0.535, 0.499)	(0.500, 0.484, 0.480)	(0.346, 0.382, 0.403)	(0.423, 0.433, 0.442)	(0.346, 0.382, 0.403)	0.0390
C46	(0.598, 0.548, 0.508)	(0.439, 0.444, 0.450)	(0.359, 0.391, 0.411)	(0.439, 0.444, 0.450)	(0.359, 0.391, 0.411)	0.0348
C51	(0.631, 0.585, 0.530)	(0.571, 0.542, 0.513)	(0.270, 0.325, 0.371)	(0.361, 0.390, 0.424)	(0.270, 0.325, 0.371)	0.0344
C52	(0.611, 0.569, 0.516)	(0.495, 0.485, 0.465)	(0.262, 0.316, 0.361)	(0.349, 0.380, 0.413)	(0.437, 0.443, 0.465)	0.0357
C53	(0.575, 0.546, 0.504)	(0.575, 0.546, 0.504)	(0.247, 0.303, 0.353)	(0.411, 0.424, 0.453)	(0.329, 0.364, 0.403)	0.0431
C54	(0.663, 0.609, 0.560)	(0.593, 0.560, 0.522)	(0.105, 0.219, 0.290)	(0.314, 0.365, 0.406)	(0.314, 0.365, 0.406)	0.0399

Using Eq. (10), we can normalise the fuzzy-decision matrix as shown in Table 5. After determining the fuzzy evaluation matrix, the third step is to obtain a fuzzy weighted decision table. Using the criteria weights calculated by FAHP (Table 2) in this step, the weighted evaluation matrix is established with Eq. (12). The resulting fuzzy weighted decision matrix is shown in Table 6.

According to Table 6, the elements $\tilde{v}_{ij}$, $\forall i, j$ are normalised positive triangular fuzzy numbers with ranges on the closed interval [0, 1]. Thus, we can define the fuzzy positive-ideal solution (FPIS, A^+) and the fuzzy negative--ideal solution (FNIS, A^-) as $\tilde{v}_i^* = (1, 1, 1)$ and $\tilde{v}_1^- = (0, 0, 0)$ for benefit criterion, and $\tilde{v}_i^* = (0, 0, 0)$ and $\tilde{v}_1^- = (1, 1, 1)$ for cost criterion. In this problem, C3 is a cost criterion whereas the other criteria are benefit criteria. For the fourth step, the distance of each warehouse location from D^+ and D^- can be calculated using Eq. (15) and Eq. (16). The fifth step solves the similarities to an ideal solution by Eq. (17) (Yang and Hung, 2007).

Table 6
Weighted normalised fuzzy decision matrix

	A	B	C	D	E
C11	(0.017, 0.015, 0.014)	(0.013, 0.013, 0.013)	(0.003, 0.006, 0.007)	(0.008, 0.009, 0.010)	(0.011, 0.011, 0.011)
C12	(0.009, 0.009, 0.009)	(0.005, 0.006, 0.007)	(0.010, 0.010, 0.010)	(0.008, 0.009, 0.009)	(0.012, 0.011, 0.011)
C13	(0.011, 0.011, 0.010)	(0.009, 0.009, 0.009)	(0.005, 0.006, 0.007)	(0.007, 0.007, 0.008)	(0.008, 0.008, 0.008)
C14	(0.009, 0.009, 0.010)	(0.011, 0.010, 0.010)	(0.006, 0.007, 0.007)	(0.008, 0.008, 0.009)	(0.011, 0.011, 0.010)
C15	(0.013, 0.014, 0.015)	(0.016, 0.016, 0.015)	(0.018, 0.018, 0.018)	(0.014, 0.015, 0.016)	(0.021, 0.020, 0.019)
C16	(0.009, 0.010, 0.011)	(0.006, 0.007, 0.009)	(0.015, 0.014, 0.014)	(0.012, 0.012, 0.012)	(0.015, 0.014, 0.014)
C17	(0.005, 0.006, 0.006)	(0.004, 0.005, 0.005)	(0.007, 0.007, 0.007)	(0.006, 0.006, 0.006)	(0.009, 0.008, 0.007)
C21	(0.039, 0.037, 0.035)	(0.044, 0.040, 0.037)	(0.007, 0.014, 0.019)	(0.014, 0.019, 0.023)	(0.021, 0.024, 0.026)
C22	(0.048, 0.046, 0.044)	(0.055, 0.050, 0.048)	(0.033, 0.036, 0.037)	(0.022, 0.029, 0.032)	(0.033, 0.036, 0.037)
C23	(0.082, 0.075, 0.068)	(0.073, 0.069, 0.066)	(0.013, 0.027, 0.035)	(0.026, 0.036, 0.042)	(0.039, 0.045, 0.049)
C31	(0.017, 0.017, 0.015)	(0.006, 0.009, 0.010)	(0.014, 0.014, 0.010)	(0.011, 0.012, 0.013)	(0.017, 0.016, 0.015)
C32	(0.014, 0.013, 0.013)	(0.011, 0.012, 0.012)	(0.016, 0.015, 0.014)	(0.012, 0.013, 0.013)	(0.012, 0.013, 0.013)
C33	(0.020, 0.018, 0.017)	(0.013, 0.013, 0.014)	(0.010, 0.012, 0.013)	(0.014, 0.014, 0.014)	(0.014, 0.014, 0.014)
C34	(0.014, 0.016, 0.018)	(0.000, 0.003, 0.007)	(0.026, 0.025, 0.024)	(0.022, 0.023, 0.023)	(0.026, 0.025, 0.024)
C35	(0.031, 0.030, 0.029)	(0.005, 0.008, 0.013)	(0.025, 0.025, 0.027)	(0.015, 0.018, 0.021)	(0.034, 0.033, 0.030)
C41	(0.022, 0.022, 0.022)	(0.022, 0.022, 0.022)	(0.013, 0.016, 0.17)	(0.028, 0.026, 0.024)	(0.013, 0.016, 0.017)
C42	(0.013, 0.012, 0.012)	(0.014, 0.013, 0.012)	(0.007, 0.008, 0.009)	(0.008, 0.009, 0.010)	(0.007, 0.008, 0.009)
C43	(0.020, 0.020, 0.020)	(0.028, 0.025, 0.024)	(0.017, 0.018, 0.019)	(0.017, 0.018, 0.019)	(0.017, 0.018, 0.019)
C44	(0.017, 0.016, 0.015)	(0.015, 0.014, 0.014)	(0.009, 0.010, 0.011)	(0.015, 0.014, 0.014)	(0.009, 0.010, 0.011)
C45	(0.022, 0.021, 0.019)	(0.019, 0.019, 0.019)	(0.013, 0.015, 0.016)	(0.016, 0.017, 0.017)	(0.013, 0.015, 0.016)
C46	(0.021, 0.019, 0.018)	(0.015, 0.015, 0.016)	(0.012, 0.014, 0.014)	(0.015, 0.015, 0.016)	(0.012, 0.014, 0.014)
C51	(0.022, 0.020, 0.018)	(0.020, 0.019, 0.018)	(0.009, 0.011, 0.013)	(0.012, 0.013, 0.015)	(0.009, 0.011, 0.013)
C52	(0.022, 0.020, 0.018)	(0.018, 0.017, 0.017)	(0.009, 0.011, 0.013)	(0.012, 0.014, 0.015)	(0.016, 0.016, 0.017)
C53	(0.025, 0.024, 0.022)	(0.025, 0.024, 0.022)	(0.011, 0.013, 0.015)	(0.018, 0.018, 0.020)	(0.014, 0.016, 0.017)
C54	(0.026, 0.024, 0.022)	(0.024, 0.022, 0.021)	(0.004, 0.009, 0.012)	(0.013, 0.015, 0.016)	(0.013, 0.015, 0.016)

To illustrate steps 4 and 5, CC_1 calculation is used as an example as follows:

$$D_1^+ = \sqrt{\tfrac{1}{3}[(1-0.017)^2+(1-0.015)^2+(1-0.014)^2]}$$
$$= \sqrt{\tfrac{1}{3}[(1-0.009)^2+(1-0.009)^2+(1-0.009)^2]}$$
$$= \sqrt{\tfrac{1}{3}[(1-0.011)^2+(1-0.011)^2+(1-0.010)^2]}$$
$$\vdots$$
$$= \sqrt{\tfrac{1}{3}[(1-0.026)^2+(1-0.024)^2+(1-0.022)^2]}$$
$$= 21.7885,$$

$$D_1^- = \sqrt{\tfrac{1}{3}[(0-0.017)^2+(0-0.015)^2+(0-0.014)^2]}$$
$$= \sqrt{\tfrac{1}{3}[(0-0.009)^2+(0-0.009)^2+(0-0.009)^2]}$$
$$= \sqrt{\tfrac{1}{3}[(0-0.011)^2+(0-0.011)^2+(0-0.010)^2]}$$
$$\vdots$$
$$= \sqrt{\tfrac{1}{3}[(0-0.026)^2+(0-0.024)^2+(0-0.022)^2]}$$
$$= 3.2506$$

$$CC_1 = \frac{D_1^-}{D_1^+ + D_1^-} = \frac{3.2506}{21.7885 + 3.2506} = 0.1298$$

Similar calculations are done for the other warehouses, and the results of fuzzy TOPSIS analyses are summarised in Table 7. Based on CC_j values, the ranking of the warehouses in descending order are *A*, *D*, *E*, *C*, and *B*. Proposed model results indicate that location *A* is the best warehouse with a *CC* value of 0.1298.

Table 7
Fuzzy TOPSIS results

Warehouses	D_j^+	D_i^-	CC_j	Rank
A	21.7885	3.2506	0.1298	1
B	21.8564	3.1753	0.1269	5
C	21.7918	3.2218	0.1288	4
D	21.7742	3.2444	0.1297	2
E	21.7802	4.2410	0.1295	3

4.4. *Sensitivity analysis*

A sensitivity analysis is realised for the two-step fuzzy AHP and fuzzy TOPSIS methodology proposed here. For this reason, the weights gained from fuzzy AHP are changed for other criteria, shifting them up one slot compared to the original results. A 24-weight change is realised during the sensitivity analysis. For example, in experiment 1, the weight of C11 (0.0255) is moved to C54, with C11 having a weight of 0.0206, which was the weight of C12. This will apply to the rest of the experiment. In experiment 24, the weight of C11 is 0.0399, and C54 is 0.0431, which were weights of C54 and C53, respectively. Then, fuzzy TOPSIS is applied to see the new results. Thus, the proposed methodology's behaviour against weight changes is observed in detail for discussion. Greater weight exchanges can be applied to expand the sensitivity analysis. Thus, the methodology result changes can be seen, which helps the user determining priorities and makes the evaluation process easier.

The results of the sensitivity analysis can be seen graphically from Figure 4, which depicts the changes in the final ranking of the solutions of warehouse locations when the weights of the criteria are changed. It can be seen from Figure 4 that out of 24 experiments, warehouse location *A* has the highest score in 21 experiments (experiments 3, 6-24). In the remaining three experiments, warehouse location *D* has the highest score in two (experiments 1-2) and warehouse location E has the highest score in experiment 4. According to the sensitivity results, *A* is determined to be the most appropriate warehouse location in 21 analyses.

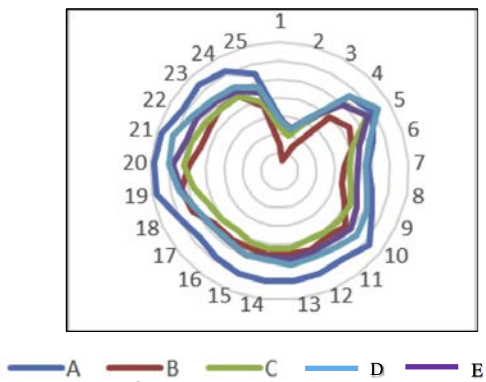

Fig. 4. Result of sensitivity analysis (CC_j scores)

5. Conclusion

Humanitarian organisations realise the importance of pre-purchasing and stocking relief items for responses to increased devastating natural and anthropogenic disasters around the world. These made their relief delivery strategies more prompt and precise to aid people in need. Different studies focused on 'what' standardised relief items to stock based on the operation characteristics of the humanitarian organisation and 'where' stock is held based on sophisticated algorithm considering security, accessibility, and various criteria.

This research implemented a two-stage fuzzy AHP and TOPSIS to identify the warehouse location factors, determine the weights applied to those factors, and evaluate warehouse location alternatives for the international humanitarian organisation to give guidance to decision-makers. The subjectivity of the ratings and evaluation standards can be considered one of the limitations of the current study. Sensitivity analysis was conducted to overcome the issue of variation in judgement from person to person or for the same individual from time to time. Through this research, it was found that national stability is considered the most important factor for warehouse selection followed by cooperation of the host country. Location A was identified as the optimal warehouse location, with Locations D and E being relatively close. The organisation primarily operates in Location A due to the high stability of the country and government incentives such as land cost and customs exemption.

The research provided participants with a tool they can use for future investigations in evaluating alternative locations and provided a more even-handed approach to a major warehouse location selection decision. Furthermore, it contributed to the literature by considering detailed warehouse location selection factors, provided insights into how international humanitarian organisations consider various factors at the country-level when making location decisions, and offered useful managerial insights related to the pre-positioning of a warehouse. The use of a robust multi-criteria decision-making framework helps in the assessment of a range of possible locations for humanitarian relief organisations.

References

BADRI, M.A. (2001), "A combined AHP-GP model for quality control systems", *International Journal of Production Economics*, Vol. 72, No. 1, pp. 27-40.

BALCIK, B. and BEAMON, B.M. (2008), "Facility location in humanitarian relief", *International Journal of Logistics: Research and Applications*, Vol. 11, No. 2, pp. 101-121.

BALCIK, B., BEAMON, B.M., KREJCI, C.C., MURAMATSU, K.M. and RAMIREZ, M. (2010), "Coordination in humanitarian relief chains: practices, challenges and opportunities", *International Journal of Production Economics*, Vol. 126, No. 1, pp. 22-34.

BEAMON, B.M. and BALCIK, B. (2008), "Performance measurement in humanitarian relief chains", *International Journal of Public Sector Management*, Vol. 21, No. 1, pp. 4-25.

BUCKLEY, J.J. (1985), "Fuzzy hierarchical analysis", *Fuzzy Sets and Systems*, Vol. 17, No. 1, pp. 233-247.

CAMPBELL, A.M. and JONES, P.C. (2011), "Prepositioning supplies in preparation for disasters", *European Journal of Operational Research*, Vol. 209, No. 2, pp. 156-165.

CHANG, D.Y. (1996), "Applications of the extent analysis method on fuzzy AHP", *European Journal of Operational Research*, Vol. 95, No. 3, pp. 649-655.

CHANG, C.W., WU, C.R. and CHEN, H.C. (2008), "Using expert technology to select unstable slicing machine to control wafer slicing quality via fuzzy AHP", *Expert Systems with Application*, Vol. 34, No. 3, pp. 2210-2220.

CHENG, C.H. (1997), "Evaluating naval tactical missile systems by fuzzy AHP based on the grade value of membership function", *European Journal of Operational Research*, Vol. 96, No. 2, pp. 343-350.

CRED (2016), 2016 preliminary data: human impact of natural disasters. http://cred.be.sites/default/files/CredCrunch45.pdf. Accessed 04 April 2017.

DEKLE, J., LAVIERI, M.S., MARTIN, E., EMIR-FARINAS, H. and FRANCIS, R.L. (2005), "A Florida country locates disaster recovery centres", *Interfaces*, Vol. 35, No. 2, pp. 133-139.

DENG, H. (1999), "Multi-criteria analysis with fuzzy pairwise comparison", *International Journal of Approximate Reasoning*, Vol. 21, No. 3, pp. 215-231.

GATIGNON, A., VAN WASSENHOVE, L.N. and CHARLES, A. (2010), "The Yogyakarta earthquake: humanitarian relief through IFRC's decentralised supply chain", *International Journal of Production Economic*, Vol. 126, No. 1, pp. 102-110.

GUMUS, T. (2009), "Evaluation of hazardous waste transportation firms by using a two-step fuzzy AHP and TOPSIS methodology", *Expert Systems with Applications*, Vol. 36, No. 1, pp. 4067-4074.

HALE, T.S. and MOBERG, C.R. (2003), "Location science research: a review", *Annals of Operational Research*, Vol. 123, Nos. 1-4, pp. 21-35.

HARTMAN, A. (1981), "Reaching consensus using the Delphi technique", *Educational Leadership*, Vol. 38, No. 6, pp. 495-497.

HSIEH, T.Y, LU, S.T. and TZENG, G.H. (2004), "Fuzzy MCDM approach for planning and design tenders selection in public office buildings". *International Journal of Project Management*, Vol. 22, No. 7, pp. 573-584.

HWANG, C.L. and YOON, K. (1981), Multiple Attribute Decision Making Methods and Applications: A State of the Art Survey, New York: Springer.

KLIBI, W., ICHOUA, S. and MARTEL, A. (2013), "Prepositioning emergency supplies to support disaster relief: A stochastic programming approach", Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation.

KOVACS, G. and SPENS, K.M. (2007), "Humanitarian logistics in disaster relief operations", *International Journal of Physical Distribution & Logistics Management*, Vol. 37, No. 2, pp. 99-114.

KUO, M.S., TZENG, G.H., and HUANG, W.C. (2007), "Group decision-making based on concepts of ideal and anti-ideal points in a fuzzy environment", *Mathematical and Computer Modelling*, Vol. 45, Nos. 3-4, pp. 324-339.

LEUNG, L.C. and GAO, D. (2000), "On consistency and ranking of alternatives in fuzzy AHP", *European Journal of Operational Research*, Vol. 124, No. 1, pp. 102-113.

LIOU, J.J.H., YEN, L. and TZENG, G.H. (2007), "Building an effective safety management system for airlines", *Journal of Air Transport Management*, Vol. 14, No. 1, pp. 20-26.

MIKHAILOV, L. (2004), "A fuzzy approach to deriving priorities from interval pairwise comparison judgement", *European Journal of Operational Research*, Vol. 159, No. 3, pp. 687-704.

MURRY, J.W. and HAMMONS, J.O. (1995), "Delphi: a versatile methodology for conducting qualitative research", *Review of Higher Education*, Vol. 18, No. 4, pp. 423-436.

RAWLS, C.G. and TURNQUIST, M.A. (2010), "Pre-positioning of emergency supplies for disaster response", *Transportation Research Part B: Methodological*, Vol 44, No. 4, pp. 521-534.

ROBBIN, S.P. (1994), Management, New Jersey: Prentice Hall.

ROH, S., PETTIT, S., HARRIS, I. and BERESFORD, A. (2015), "The pre-positioning of warehouse at regional and local levels for humanitarian relief organization", *International Journal of Production Economics*, Vol. 170, No. B, pp. 616-628.

SAATY, T.L. (1980), Fundamentals of Decision Making and Priority-Theory with the Analytic Hierarchy Process, Pittsburgh: RWS Publications.

SALISBURY, D. (2007), Personal interview, (2 April 2004) In: BALCIK, B. and BEAMON, B.M. (2008), "Facility location in humanitarian relief", *International Journal of Logistics: Research and Application*, Vol. 11, No. 2, pp. 101-121.

SCOTT-BOWDEN, P. (2003), "The world food programme: augmenting logistics", *Forced Migration Review*, Vol. 18, pp. 17-19.

STRASH, R. (2004), Personal interview, (2 April 2004) In: BALCIK, B. and BEAMON, B.M. (2008), "Facility location in humanitarian relief", *International Journal of Logistics: Research and Application*, Vol. 11, No. 2, pp. 101-121.

THOMAS, A.S. (2002), "Supply chain reliability for contingency operations", Proceedings of the Annual Reliability and Maintainability Symposium, pp. 61-67.

TORFI, F., FARAHANI, R.Z and REZAPOUR, S. (2010), "Fuzzy AHP to determine the relative weights of evaluation criteria and Fuzzy TOPSIS to rank the alternatives", *Applied Soft Computing*, Vol. 10, No. 2, pp. 520-528.

UKKUSURI, S. and YUSHIMOTO, W. (2008), "Location routing approach for the humanitarian prepositioning problem", *Transportation Research Record*, Vol. 2089, pp. 18-25.

UNDHA (United Nations Department of Humanitarian Affairs). (1994), Study on Emergency Stockpiles. http://reliefweblint/ocha_ol/programs/response/stocknetStudyE.html#factors. Accessed April 7, 2017.

VAN WASSENHOVE, L.N. (2006), "Humanitarian aid logistics: supply chain management in high gear", *Journal of the Operational Research Society*, Vol. 57, No. 5, pp. 475-489.

ZADEH, L.A. (1965), "Fuzzy sets", *Information and Control*, Vol. 8, No. 3, pp. 338-353.

ZADEH, L.A. (1975), "The concept of a linguistic variable and its application to approximate reasoning", *Information Sciences*, Vol. 8, pp. 199-249(I), 301-357(II).