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Fuzzy multi-attribute group decision making to identify the order of establishing temporary logistics hubs during disaster response

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Abstract

Purpose – The purpose of this paper is to reveal the importance of the order of establishment of temporary logistics hubs (TLHs) when resources (mobile storage units used as TLHs) are limited and to present the development and implementation of a methodology that determines the order of establishment of TLHs to support post-disaster decision making.

Design/methodology/approach – It employed a decision support system that considers multiple decision makers and subjective attributes, while also addressing the impreciseness inherent in post-disaster decision making for ordering the establishment of TLHs. To do so, an optimization model was combined with a fuzzy multi-attribute group decision making approach. A numerical illustration was performed using data from the April 2015 Nepal Earthquake.

Findings – The results showed the location and order of establishment of TLHs, and demonstrated the impact of decision makers' opinions on the overall ordering.

Research limitations/implications – The study does not discuss the uncertain nature of the location problem and the potential need for relocation of TLHs.

Practical implications – This methodology offers managerial insights for post-disaster decision making when resources are limited and their effective utilization is vital. The results highlight the importance of considering the opinions of multiple actors/decision makers to enable coordination and avoid complication between the growing numbers of humanitarian responders during disaster response.

Originality/value – This study introduces the concept of the order of establishment of TLHs and demonstrates its importance when resources are limited. It develops and implements a methodology determining the order of establishment of TLHs to support post-disaster decision making.

Keywords Humanitarian supply chain, Facility location problem, Temporary logistics hub, Emergency relief, Multi-attribute group decision making, Order of establishment

Paper type Research paper

Nomenclature

T	set of time periods
I	set of supply points
J	set of temporary logistic hubs (TLHs)
K	set of affected area demand points
QS_{it}	maximum available quantity of emergency relief materials at supply point $i \in I$ in period t (kg)
QH_{jt}	maximum available quantity of emergency relief materials at TLH $j \in J$ in period t (kg)
d_{kt}	demand of the affected area's demand point k in period t (kg)

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n_{kt}	number of TLHs allocated to demand point k in period t
M	a very large number
P	total number of TLHs
r_{ijt}	amount of emergency relief materials shipped from supply point $i \in I$ to TLH $j \in J$ in period $t \in T$
q_{jkt}	amount of emergency relief materials shipped from TLH $j \in J$ to the affected area's DP $k \in K$ in period $t \in T$
y_j	binary variable that equals 1 if the facility at j is selected as a TLH and 0 otherwise
z_{jkt}	binary variable that equals 1 if TLH j serves demand point k in period t and 0 otherwise

1. Introduction

Effective disaster salvage requires implementing different disaster response facilities immediately after a disaster has occurred. Of the numerous types of facilities prevalent in humanitarian operations, this study focuses on those intended for relief distribution. These facilities can be categorized as permanent or temporary based on the length of their operational horizon. Permanent facilities operate before the disaster and have long or even infinite operational horizons, whereas temporary response facilities only operate once the location of the disaster is known and have a short operational horizon. While determining the location for a permanent facility is a strategic decision, doing so for a temporary facility is a tactical/operational decision with which decision makers are faced after a disaster.

The appropriateness of a logistics hub's location can determine the success or failure of a humanitarian relief operation. However, the unpredictability of disasters makes it difficult to ascertain the precise location of logistics hubs beforehand. Moreover, high inventory holding costs, as well as limited funds and operating resources, often restrict the number of permanent facilities. Therefore, the temporary nature of such facilities is an indispensable part of humanitarian relief operations (Maharjan and Hanaoka, 2018). A temporary logistics hub (TLH) is defined as a place designated for the storing, sorting, consolidating, deconsolidating and distributing of emergency relief materials to disaster-affected areas in the short term. They act as an intermediator between the central warehouse or relief supply points and the affected areas in need of emergency relief.

A typical location problem includes ascertaining the number, spatial location and the allocation of demand for open facilities. However, locating TLHs during disaster response also requires determining the order of establishment of the facilities when resources are limited. Often mobile storage units that can be easily assembled, disassembled and transported are used as TLHs. Fire retardant, waterproof, rot proof and UV stabilized, these mobile storage units too are usually expensive to be stockpiled in large quantities. During the initial response stage of The 2015 Nepal Earthquake, the number of mobile storage units available in country was limited, which resulted in the effective establishment of regional logistics hubs facing several hindrances, including delay and mobile storage units having insufficient capacity.

In location decision making, traditional network models take into account quantitative factors and aim to minimize the total cost or to maximize profitability or coverage. Non-quantitative criteria, such as work force qualifications, geographical characteristics and road networks, are also important in deciding location. In the aftermath of a disaster, the decision making process typically involves multiple decision makers with varying interests and opinions. Indeed, the growing complexity and uncertainty of decision situations make it less and less possible for a decision maker to consider all the relevant aspects of a problem, thereby necessitating the participation of multiple experts in the decision making process (Ben-Arieh and Chen, 2006). As such, achieving a proper balance among them is a significant challenge. Furthermore, disaster response operation in most emerging countries is resource constrained and requires the effective allocation of resources to ensure their effective utilization. While optimization approaches can be used for evaluating quantitative factors, this evaluation of qualitative factors is often accompanied by ambiguity and vagueness (Önüt *et al.*, 2010). This is particularly so in the aftermath of a disaster, when the environment is chaotic, and there is limited information and time. Moreover, Montibeller and Yoshizaki (2011) state that intangible factors can change a network configuration resulting from a mathematical model. Essentially, disaster managers have to make myriad reactive operational decisions to solve complex dilemmas with little to no information under immensely stressful conditions as they respond to emergencies. This highlights the need for a simple and inclusive methodology. Under these circumstances, an appropriate decision making strategy would require that the resolutions and opinions of a group of decision makers be taken into account when evaluating the subjective and objective attributes in the TLH selection process.

This study seeks to address the gaps in the existing literature and aid in the decision making process by developing a methodology that determines the order of establishment of TLHs, and which considers location problems in doing so. The proposed methodology operates in three stages. The first stage uses an optimization model to determine the number and spatial location of the TLHs. In the second stage, a fuzzy factor rating system under group decision making is used to rate the importance of attributes. Finally, in the third stage, a fuzzy multi-attribute group decision making approach is used to determine the order of establishment of selected TLHs. As the humanitarian code of conduct dictates that humanitarian imperative comes first such that the prime motivation of response to disaster is to alleviate human suffering (Code of Conduct, 1994). In line with the humanitarian code of conduct, the optimization model in the first stage minimizes total unsatisfied demand. This is in contrary to common approach of minimizing costs which has been adopted by recent studies (Lin *et al.*, 2012; Khayal *et al.*, 2015; Cavdur *et al.*, 2016; Stauffer *et al.*, 2016) focusing on temporary facilities. Moreover, a personal interview with the logistics expert working in non-governmental organization stated that minimizing unsatisfied demand should be the primary objective as humanitarian operations are based on donations.

As such, the objectives, and contributions, of this study are threefold. Introducing the concept of the order of establishment of TLHs, this study develops and implements a three-stage methodology aimed at the effective utilization of mobile storage units when their availability is scarce. Second, this study shows that amalgamating an optimization model with the multi-attribute decision making approach enables the evaluation of both subjective and objective attributes, and has enhanced applicability to real-life scenarios. Third, this study illustrates the value of applying fuzzy linguistic variables to deal with the vagueness and imprecision inherent in evaluating subjective attributes in post-disaster decision making that involves multiple decision makers. To support this methodology and contributions, this study implements a numerical illustration using data from a real-life disaster – The Nepal Earthquake (2015).

In achieving this, the remainder of this paper is organized as follows. A review of the relevant literature is provided in the next section. Section 3 presents the TLH location selection model and the corresponding formulation for determining the order of establishment of the selected facilities. Using disaster data from The Nepal Earthquake (2015), a numerical illustration of the proposed methodology is demonstrated in Section 4. Finally, Section 5 discusses the contributions and conclusions of this study.

2. Literature review

As one of the core problems in the humanitarian relief chain, facility location is receiving burgeoning attention in the literature – as evidenced by the growing number of studies focused on this topic. Studies centered on location planning for humanitarian logistics issues have targeted at different phases of disaster using different approaches to determine the location of key facilities. Studies focusing on pre-positioning have been conducted by

Balcik and Beamon (2008), Rawls and Turnquist (2010, 2012), Galindo and Batta (2013), Rennemo *et al.* (2014), Salman and Yücel (2015), Pradhananga *et al.* (2016), Beskaya *et al.* (2017), Maharjan and Hanaoka (2017) and Yahyaei and Bozorgi-Amiri (2018) with the objective of minimizing costs in most cases.

Amid the studies focusing on location planning for post-disaster phase, Döyen *et al.* (2012), Ahmadi *et al.* (2015), Pradhananga *et al.* (2016), Zokaee *et al.* (2016) and Yahyaei and Bozorgi-Amiri (2018) determined the location with the objective of minimizing total costs. Similarly, Lin *et al.* (2012) and Khayal *et al.* (2015) minimized logistics and penalty costs in doing so. While Cavdur *et al.* (2016) determined location with the aim of minimizing different forms of costs, Stauffer *et al.* (2016) minimized total vehicular costs over the planning period. Contrary to popular cost minimization approach, Rennemo *et al.* (2014) maximized utility, whereas Afshar and Haghani (2012) minimized total weighted unsatisfied demand. It is worth to note that all these studies use a purely quantitative approach based on optimization for location selection process. Moreover, only a limited number of studies focus on temporary facilities through recourse to an optimization approach usually with the objective of minimizing total cost; a detailed review of these studies is provided by Maharjan and Hanaoka (2018).

Of the various ways with which to deal with the problem of facility location, optimization and multi-criteria decision making are the approaches used most frequently in humanitarian logistics. While several studies have used these two approaches separately, Ortuño *et al.* (2013) argued that a decision support system incorporating optimization tools needs to be used to enhance applicability in real life. Within studies that have adopted a qualitative or a combined (qualitative and quantitative) approach, several attributes have been considered governing factors in location selection problem. Bozorgi-Amiri and Asvadi (2015) proposed a decision support system for prioritizing the location of regional logistic centers that considers availability, risk, technical issues, cost and coverage. To do so, they used lexicographic goal programming and two-step logarithmic goal programming to derive priorities from pair-wise matrices. Roh *et al.* (2015) provided insights into important factors at each level when making location decisions. They use a two-stage analytic hierarchy process (AHP) and fuzzy technique for order preference, by similarity to ideal solution (TOPSIS) methodology to rank location alternatives where linguistic variables handle the vagueness and subjectivity of decisions. Gutjahr and Nolz (2016) grouped the optimization criteria used in humanitarian aid into seven categories: cost, travel distance, coverage, reliability, security, equity and distress. Trivedi and Singh (2017) applied fuzzy AHP and goal programming to determine the location of emergency shelter sites. They used the following as key criteria for location selection: favorability of terrain, electrical infrastructure, hygiene and sanitation systems, community infrastructure, safety and security, transportation capacity, proximity and type of ownership.

Known for its utility in evaluating imprecise attributes, the fuzzy multi-attribute group decision making approach uses fuzzy set theory to deal with the vagueness and imprecision in decision making. It also uses the logic and principle of the simple additive weighing method in factor rating systems to derive total scores for individual alternatives, which allows ranking by order of preference (Heragu, 1997; Heizer and Render, 2004) in group decision making conditions. This approach has been proven simple yet efficient in dealing with the qualitative dimensions of alternative selection problem by Chou *et al.* (2008). Fuzzy simple additive weighing has been used by several researchers like Chou *et al.* (2008) to evaluate facility location alternatives, Modarres and Sadi-Nezhad (2005) for multi-attribute decision making, Wang (2015) to find the best alternative from feasible alternatives and Abdullah *et al.* (2018) for ambulance location. A simulation by Zanakis *et al.* (1998) evaluated eight multi-attribute decision making methods: simple additive weighing; multiplicative exponential weighting (MEW); TOPSIS; elimination and (et) choice translating reality (ELECTRE); and four AHPs. The rank-reversal dimension indices in the simulation disclosed that SAW and MEW performed the best, followed by TOPSIS and AHPs. The ELECTRE method performed the worst. In addition, Chang and Yeh (2001) confirmed the superiority of simple additive weighing in an empirical study of the three evaluation methods (simple additive weighing method, weighted product method and TOPSIS). The findings of these studies suggest the superiority of SAW method.

Furthermore, while we are unsuccessful in making quantitative predications, we are comparatively efficient at qualitative forecasting. Fuzzy decision theories attempt to deal with the vagueness, that is, fuzziness, inherent in the subjective or imprecise determination of preferences, constraints and goals (Yager and Filev, 1994). In addition to its abundant application in commercial logistics, fuzzy group decision making is a popular approach used for facility location problems (cf. Kahraman *et al.*, 2003; Chou *et al.*, 2008; Ertuğrul, 2011). However, their application in humanitarian logistics is nominal.

Facility location for humanitarian relief operations is receiving growing attention and has been relatively well researched in humanitarian operations. Within the extant literature, there is a general lack of studies that amalgamate optimization with a multi-criteria decision making approach, which enables assessing both qualitative and quantitative aspects to model location problem. On the one hand, studies using an optimization approach to the problem of location selection hardly include qualitative attributes. On the other hand, studies focusing on location selection by incorporating qualitative attributes barely focus on the temporary nature of disaster response facilities and the need to incorporate optimization techniques. Although there is abundant literature, there is also a scarcity of studies that concentrate on issues related to ordering the establishment of TLHs in addition to their location and allocation strategies when the resources are limited. Moreover, few studies focus specifically on temporary facilities for relief distribution. Indeed, while the study of Maharjan and Hanaoka (2018) has incorporated multiple decision makers in a multi-objective optimization for TLH location selection, it does not consider the order of its establishment.

As such, this study aims to develop a methodology that determines the order of establishment of TLHs that incorporates an optimization model and a multi-criteria decision making approach. The methodology allows evaluating quantitative aspects and several qualitative attributes while considering the temporary nature of disaster response facilities under the presence of multiple actors.

3. Model formulation

Consider the occurrence of a large-scale disaster that causes significant infrastructural damage and injury and results in large number of affected people. The scale of the disaster will attract responses from different humanitarian, governmental and non-governmental organizations, as well as local community groups, thereby creating a multi-actor scenario. Depending on the scale of the disaster, the number of humanitarian actors can range from a few dozens to several hundred. Effective disaster response requires the establishment of TLHs that can manage, sort and store incoming emergency relief materials intended for distribution to affected people in different geographical locations immediately after the disaster. In large-scale disasters, we can assume a situation where the mobile storage units used as TLHs are limited in number in the immediate aftermath. To facilitate the response to urgent emergency relief demands in affected areas while enabling the effective utilization of scarce mobile storage units, this study develops a mechanism to determine the order of establishment of TLHs.

Based on the aforementioned prerequisites, the methodology for determining the order of establishment of TLHs involves the following: an optimization model, to calculate the number and the spatial location of TLHs; a mechanism establishing the importance weight of the subjective attributes; and a fuzzy multi-attribute group decision making approach, to ascertain their order of establishment. In the first stage, the optimization model calculates the location alternatives for TLHs by minimizing total unsatisfied demand over the entire planning horizon. Moreover, to select an appropriate location, several qualitative attributes – including the availability of work force, basic infrastructure facilities, security and accessibility issues – need to be evaluated immediately after a disaster has occurred. While quantitative factors can be modeled using optimization techniques, qualitative factors are often difficult to incorporate and evaluate. As such, the main purpose of the second mechanism is to synthesize the importance weight of the attributes that will be used to evaluate the resulting location alternatives when multiple decision makers exist. Finally, in the third step, the results obtained from the first-stage optimization model are used as alternatives for subjective evaluation. The last two steps can be operated recursively to accommodate the varying numbers and opinions of decision makers. This methodology is, thus, a development of that of Maharjan and Hanaoka (2018), and is intended to assist decision makers in the design of emergency logistics plan. The next subsection provides the details of each mechanism.

3.1 Selection of location alternatives for TLHs

This mechanism aims to determine the number and spatial location of TLHs. We have formulated an optimization model with the objective of minimizing total unsatisfied demand under dynamic demand and changing level of available emergency relief. The proposed approach allows us to accurately capture the changing levels of relief demand and supplies over the planning horizon. Within this optimization model, the establishment of TLHs is required to meet the demand of affected people over the entire relief time horizon. Each district or demand point has an associated demand for emergency relief materials. A demand point represents the aggregated demands of one district. Along the discrete time horizon, demands from the affected zone changes in a known way related to information availability, changes in the number of affected people and the recovery of affected people – and demand can increase, decrease or stagnate as a consequence. The amount of emergency relief materials available in TLHs is affected by its capacity, as well as external availability issues. This amount can be less than or equal to the capacity of TLHs – that is, it cannot exceed the capacity of TLHs. Our model is deterministic – the location and the affected areas of the disaster are known before the decision to open a TLH is made. The following section provides further detail of the mathematical model, parameters and variables.

The optimization problem is formulated as follows.

Minimize:

$$\sum_k \sum_t d_{kt} - \sum_j \sum_k \sum_t q_{jkt} \tag{1}$$

Constraints:

$$\sum_k q_{jkt} = \sum_i r_{ijt} \quad \forall j \in J,\ t \in T \tag{2}$$

$$\sum_j r_{ijt} \leqslant QS_{it} \quad \forall i \in I,\ t \in T \tag{3}$$

$$\sum_i r_{ijt} \leqslant QH_{jt} \quad \forall j \in J,\ t \in T \tag{4}$$

$$\sum_{k} q_{jkt} \leqslant QH_{jt} \quad \forall j \in J,\ t \in T \tag{5}$$

$$\sum_{j} y_j \leqslant P \tag{6}$$

$$\sum_{j} q_{jkt} \leqslant d_{kt} \quad \forall k \in K,\ t \in T \tag{7}$$

$$z_{jkt} \leqslant y_j \quad \forall j \in J \tag{8}$$

$$\sum_{j} z_{jkt} \leqslant n_{kt} \quad \forall k \in K,\ t \in T \tag{9}$$

$$q_{jkt} \leqslant M z_{jkt} \quad \forall j \in J,\ t \in T \tag{10}$$

$$r_{ijt} \geqslant 0 \quad \forall i \in I,\ j \in J,\ t \in T \tag{11}$$

$$q_{jkt} \geqslant 0 \quad \forall j \in J,\ k \in K,\ t \in T \tag{12}$$

$$y_j \in \{0,1\} \quad \forall j \in J \tag{13}$$

$$z_{jkt} \in \{0,1\} \quad \forall j \in J,\ k \in K,\ t \in T \tag{14}$$

The objective function (1) minimizes total unsatisfied demand. Constraint (2) is the flow conservation constraint. Constraints (3)–(5) are the availability constraints. Constraint (3) ensures that the quantity of emergency relief materials moved from the supply points to the TLHs should be less than or equal to the maximum available quantity of emergency relief materials in the supply point in each period. Similarly, constraints (4) and (5) ensure that the quantity of emergency relief materials moved from the supply points to the TLHs and from TLHs to the demand points of affected areas should be less than or equal to the maximum available quantity of emergency relief materials in the TLHs in each period. Constraint (6) limits the total number of TLHs. Constraint (7) ensures that the quantity of emergency relief delivered to each demand point does not exceed its demand. Constraint (8) ensures that a demand point is served by TLH only if the TLH is open. Constraint (9) enforces multi-sourcing, ensuring that each demand point is served by a pre-specified number of TLHs. Constraint (10) obligates emergency relief distribution only between the assigned TLH and the demand point. Constraints (11)–(14) express the nature of the decision variables used in the model.

3.2 Determining the importance weight of attributes

The main purpose of this stage is to determine the importance weight of the subjective attributes used in evaluating TLH location alternatives. In this study, we adapted the “fuzzy factor rating system under group decision making condition” developed by Maharjan and Hanaoka (2018) to accommodate the calculation of the importance weights of subjective attributes. The fuzzy factor rating system under group decision making uses fuzzy logic to account for the inherent vagueness and uncertainty associated with decision making during disaster response. Fuzzy logic allows impersonating ambiguous and uncertain linguistic knowledge and offers a robust framework for model designers dealing with systems that contain high uncertainty (Aguilar-Lasserre *et al.*, 2009). Trapezoidal fuzzy numbers are the most widely used form of fuzzy numbers because they can be handled arithmetically and interpreted intuitively (Chou *et al.*, 2008). Hence, the linguistic terms assessing scarcely quantifiable variables are represented by trapezoidal fuzzy numbers in this study. The modified mechanism is composed of six sequential steps, explained hereunder.

- Step 1: selection of attributes

  Several attributes play an important role in determining the order of establishment of TLHs. In this study, the term "attribute" is used to refer to subjective attributes only. The attributes can be selected based on a variety of criteria, including the socio-economic situation of the country, the geo-climatic situation, a literature survey and a review of lessons learned from the reports of past disasters. The attributes should be selected to ensure the sound utility and operational sustainability of the TLHs.

- Step 2: selection of decision makers

  Under the GDM scenario, multiple decision makers can be chosen. The choice of decision makers also varies from case to case and country by country. A committee of decision makers can be formed based on their overall role in the disaster management activity. The nature of these decision makers and their decision opinions can lead to the generation of different scenarios: when the decision makers are homogeneous, their decision opinions are homogeneous or their decision opinions are heterogeneous; when the decision makers are heterogeneous, their decision opinions are homogeneous or their decision opinions are heterogeneous.

- Step 3: determining the degree of importance of decision makers

  As such, the next step is to determine if decision makers are homogeneous or heterogeneous. If the degree of the importance of decision makers is equal, then the group of decision makers is deemed a homogeneous group; otherwise, the group is deemed heterogeneous.

  In a committee of k decision makers (D_t, $t=1, 2, \ldots, k$) responsible for assessing m alternatives (A_i, $i=1, 2, \ldots, m$), under each of the n attributes (C_j, $j=1, 2, \ldots, n$), as well as importance of attributes, the degree of importance of the decision makers is I_t, $t=1, 2, \ldots, k$, where $I_t \in [0, 1]$ and $\sum_{t=1}^{k} I_t = 1$. If $I_1 = I_2 = \cdots = I_k = 1/k$, the group of decision makers is called a homogeneous group; otherwise, the group is called a heterogeneous group. The importance of each decision maker can be determined by interviewing the final decision maker or based on their role in overall disaster management activities.

- Step 4: collecting decision opinions and computing the aggregated fuzzy rating of individual attributes

  The decision opinions of decision makers can be obtained using a questionnaire interview or in person. The questionnaire uses the linguistic variables outlined in Table I to enable decision makers to assess the importance of the attributes. Table I is

Table I.
Linguistic variables and fuzzy numbers

Linguistic variables	Fuzzy numbers
Very low (VL)	(0, 0, 0, 3)
Low (L)	(0, 3, 3, 5)
Medium (M)	(2, 5, 5, 8)
High (H)	(5, 7, 7, 10)
Very high (VH)	(7, 10, 10, 10)

used for rating in the manner employed by Liang and Wang (1991), Liang (1999), Yong (2006) and Chou *et al.* (2008). Subsequently, to compute the aggregated fuzzy rating of the individual attributes, let $\tilde{W}_{jt} = (a_{jt}, b_{jt}, c_{jt}, d_{jt}), j = 1, 2, \ldots, n; t = 1, 2, \ldots, k$, be the linguistic rating given to attributes $C_1, C_2, \ldots, C_n$ by decision maker D_t. The aggregated fuzzy rating, $\tilde{W}_j = (a_j, b_j, c_j, d_j)$, of attribute C_j assessed by the committee of k decision makers is defined as follows:

$$\tilde{W}_j = \left(I_1 \otimes \tilde{W}_{j1}\right) \oplus \left(I_2 \otimes \tilde{W}_{j2}\right) \oplus \cdots \oplus \left(I_k \otimes \tilde{W}_{jk}\right) \qquad (15)$$

where $a_j = \sum_{t=1}^{k} I_t a_{jt}$, $b_j = \sum_{t=1}^{k} I_t b_{jt}$, $c_j = \sum_{t=1}^{k} I_t c_{jt}$, $d_j = \sum_{t=1}^{k} I_t d_{jt}$.

- Step 5: computing the importance weight of attributes

  This step is to compute the importance weight of attributes, defuzzify the fuzzy rating of the individual attributes, compute the normalized weights and construct the weight vector. To defuzzify the rating of the fuzzy attributes, the signed distance is adopted. The defuzzification of $\tilde{W}_j$, denoted as $d(\tilde{W}_j)$, is therefore given by:

$$d\left(\tilde{W}_j\right) = \frac{1}{k}\left(a_j + b_j + c_j + d_j\right) \qquad (16)$$

The crisp value of the normalized weight for attributes C_j, denoted by W_j, is given by:

$$W_j = \frac{d\left(\tilde{W}_j\right)}{\sum_{j=1}^{n} d\left(\tilde{W}_j\right)} \qquad (17)$$

where $\sum_{j=1}^{n} W_j = 1$. The weight vector $W = [W_1, W_2, \ldots, W_n]$ is therefore formed.

The crisp value of the normalized weight of the attributes C_j can, thus, be used as the importance weight of the attributes.

3.3 Identifying the order of establishment of TLHs

To facilitate the establishment of TLHs, this stage aims to determine the order in which TLHs should be established. To do so, a fuzzy multi-attribute group decision making approach uses the qualitative attributes selected in the second stage to evaluate each TLH location alternative obtained from the first stage. The following summarizes the main steps involved in this fuzzy multi-attribute group decision making method:

- Step 1: obtain the decision opinions of decision makers to assess alternatives with respect to individual attributes, and obtain aggregated fuzzy ratings

  This step is to assess the fuzzy ratings of location alternatives with respect to individual attributes, obtain the decision opinions of decision makers using the linguistic variables outlined in Table II, and pool them together to obtain the aggregated fuzzy ratings. Table II is used for rating in the manner employed by Liang and Wang (1991), Liang (1999), Yong (2006) and Chou *et al.* (2008). An interview questionnaire can be used for the rating of alternatives.

  Let $\tilde{x}_{ijt} = (o_{ijt}, p_{ijt}, q_{ijt}, r_{ijt})$, $i=1, 2, \ldots, m$; $j=1, 2, \ldots, n$; $t=1, 2, \ldots, k$, be the linguistic suitability rating assigned to alternatives A_i for attributes C_j by decision maker D_t. The aggregated fuzzy rating $\tilde{x}_{ij}$ of alternative A_i for attribute C_j assessed by the committee of k decision makers is defined as follows:

$$\tilde{x}_{ij} = \left(I_1 \otimes \tilde{x}_{ij1}\right) \oplus \left(I_2 \otimes \tilde{x}_{ij2}\right) \oplus \cdots \oplus \left(I_k \otimes \tilde{x}_{ijk}\right). \qquad (18)$$

This can subsequently be represented and computed as follows:

$$\tilde{x}_{ij} = \left(o_{ij}, p_{ij}, q_{ij}, r_{ij}\right), i = 1, 2, \ldots, m,\ j = 1, 2, \ldots, n,$$

where $o_{ij} = \sum_{t=1}^{k} I_t o_{ijt}$, $p_{ij} = \sum_{t=1}^{k} I_t p_{ijt}$, $q_{ij} = \sum_{t=1}^{k} I_t q_{ijt}$, $r_{ij} = \sum_{t=1}^{k} I_t r_{ijt}$.

- Step 2: construct a fuzzy rating matrix

  The fuzzy rating matrix $\tilde{\mathrm{M}}$ can be constructed based on fuzzy ratings, and expressed concisely in the matrix format:

$$\tilde{\mathrm{M}} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}$$

where $\tilde{x}_{ij}$, $\forall i, j$ is the aggregated fuzzy rating of alternative A_i with respect to attribute C_j.

- Step 3: derive the total fuzzy scores for individual alternatives by multiplying the fuzzy rating matrix by its respective weight vectors

  Obtain the total fuzzy score vector by multiplying the fuzzy rating matrix $\tilde{\mathrm{M}}$ by the corresponding weight vector W, i.e.:

$$\tilde{\mathrm{F}} = \tilde{\mathrm{M}} \otimes \mathrm{W}^T = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \ldots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \otimes \begin{bmatrix} \mathrm{W}_1 \\ \mathrm{W}_2 \\ \vdots \\ \mathrm{W}_n \end{bmatrix}$$

$$= \begin{bmatrix} \tilde{x}_{11} \otimes \mathrm{W}_1 \oplus \tilde{x}_{12} \otimes \mathrm{W}_2 \oplus \cdots \oplus \tilde{x}_{1n} \otimes \mathrm{W}_n \\ \tilde{x}_{21} \otimes \mathrm{W}_1 \oplus \tilde{x}_{22} \otimes \mathrm{W}_2 \oplus \cdots \oplus \tilde{x}_{2n} \otimes \mathrm{W}_n \\ \vdots \\ \tilde{x}_{m1} \otimes \mathrm{W}_1 \oplus \tilde{x}_{m2} \otimes \mathrm{W}_2 \oplus \cdots \oplus \tilde{x}_{mn} \otimes \mathrm{W}_n \end{bmatrix} = \begin{bmatrix} \tilde{f}_1 \\ \tilde{f}_2 \\ \vdots \\ \tilde{f}_m \end{bmatrix} = \left[\tilde{f}_i\right]_{m \times 1} \tag{19}$$

where $\tilde{f}_i = (s_i, t_i, u_i, v_i)$.

- Step 4: compute the crisp values using a defuzzification method

  Defuzzify the fuzzy scores $\tilde{f}_1, \tilde{f}_2, \ldots, \tilde{f}_m$ by using signed distance method (Yao and Wu, 2000). It is a popular method used for defuzzifying fuzzy numbers. It has been used by several literatures (Yao and Chiang, 2003; Syed and Aziz, 2007;

Table II.
Linguistic variables and fuzzy numbers for ratings

Linguistic variables	Fuzzy numbers
Very poor	(0, 0, 0, 20)
Between very poor and poor	(0, 0, 20, 40)
Poor	(0, 20, 20, 40)
Between poor and fair	(0, 20, 50, 70)
Fair	(30, 50, 50, 70)
Between fair and good	(30, 50, 80, 100)
Good	(60, 80, 80, 100)
Between good and very good	(60, 80, 100, 100)
Very good	(80, 100, 100, 100)

Chou and Chang, 2008; Lin and Lee, 2010) in diverse fields since its development. The signed distance method has been proven to be effective by Lin and Lee (2010). The following defuzzification equation is used to determine the crisp total scores of individual locations:

$$d\left(\tilde{f}_i\right) = \frac{1}{4}(s_i + t_i + u_i + v_i) \quad i = 1, 2, \ldots, m, \tag{20}$$

where $d(\tilde{f}_i)$ gives the defuzzified value (crisp value) of the total fuzzy score of location alternative A_i.

- Step 5: determine the order of establishment of the TLHs

  Finally, this step is to determine the order of establishment of TLHs, and rank the location alternatives based on the crisp values. The location alternatives with larger crisp values should be established first, followed by the location alternatives with lower values. The higher crisp value indicates the better performance of alternatives over the selected attributes.

4. Numerical illustration and analysis

To support the usefulness of this methodology, a numerical experiment was performed using disaster data from The Nepal Earthquake (2015). On April 25, 2015, a 7.8 magnitude earthquake occurred in Barpak in the Gorkha district, which is approximately 78 km northwest of the capital city, Kathmandu. Aftershocks occurred for weeks after the initial earthquake. The earthquake resulted in roughly 8,790 deaths and 22,300 injuries, while some 773,174 houses were destroyed (501,783) or damaged (271,391) (NPC, 2015). As many as 450 humanitarian aid groups contributed to relief efforts in multiple ways by facilitating rescue, evacuation, relief distribution, rehabilitation and recovery (UNOCHA, 2015). A number of governmental, non-governmental, national and international organizations conducted large-scale operations in the 14 most affected districts.

The humanitarian supply chain during the immediate aftermath of the earthquake faced many challenges such as the lack of vehicles, congestion in the airport, the lack of coordination and cooperation and operational and location issues related to the use of regional logistics hubs (WFP, 2016). Disaster response proved extremely difficult due to the large scale of the devastation, huge number of responders, manifold interests of multiple organizations and infrastructural difficulties in accessing affected zones, poor weather conditions and limited resources. Apart from the inevitable challenges, many criticized the Nepalese Government for its lack of preparedness, which caused relief supplies to pile up at the airport (*The New York Times*, 2015; *Disaster Recovery Journal*, 2015). To facilitate the receipt of relief items and onward delivery and intermediate storage, nine storage hubs located in Gorkha, Kathmandu, Chitawan, Dhading, Kavrepalanchok, Nuwakot, Rasuwa, Sindhupalchok and Dolakha were established in Kathmandu and the most affected areas; the establishment of which faced abundant challenges (WFP, 2016) including lack of equipment like forklifts.

4.1 Optimal number and the spatial location of TLHs

To determine the optimal number and location of TLHs, we considered 7 supply points, 11 candidate TLHs and 13 demand points. The optimal solution was achieved by minimizing total unsatisfied demand over the entire planning horizon. An operational horizon of five weeks was considered with each period lasting one week. We accounted for a single package relief delivery system. A single emergency relief package was assumed to weigh 10 kg and to include essential items such as meals, a basic medical kit, blankets, baby supplies and clothing. We estimated that a single emergency relief package is sufficient to sustain an individual for a week. The demand, cost and available units of relief supplies are assumed dynamic.

The model was coded using Lingo 17.0 Optimization modeling software. All the experiments were run on a personal computer with an Intel (R) Core (TM) i5-7500 CPU (3.40 GHz) and 16 GB of RAM. All the test problems were computed in under 10 min. Under the given conditions, the model resulted in six TLHs with locations in Dolakha, Gorkha, Kathmandu, Makwanpur, Okhaldhunga and Sindhupalchok. Figure 1 shows the spatial location of the selected TLHs on a map of Nepal.

4.2 Determining the importance weight of attributes

Eight attributes were identified through a combination of a survey of the literature on the problem of facility location in humanitarian operations; the lessons learnt reports published by different entities, as well as information regarding the socio-economic and geo-climatic context of Nepal. Table III lists and describes the selected attributes.

A committee of four decision makers – D_1, D_2, D_3, and D_4 – from four humanitarian organizations active in disaster management in Nepal was formed. The decision makers involved in evaluating the qualitative attributes were assumed homogeneous – the degree of importance is thus equal for all the decision makers.

Table IV shows the decision opinions of four decision makers using the linguistic weighing variables. The aggregated fuzzy rating of individual attributes was computed using Equation (15) with reference to fuzzy numbers corresponding to each linguistic variable (Table I). The importance weight of the attributes was calculated by defuzzifying the fuzzy numbers using the signed distance approach represented by Equation (16), and the normalized weight was calculated using Equation (17). The aggregated fuzzy weight, crisp values after defuzzification and the normalized weight are shown in Table IV.

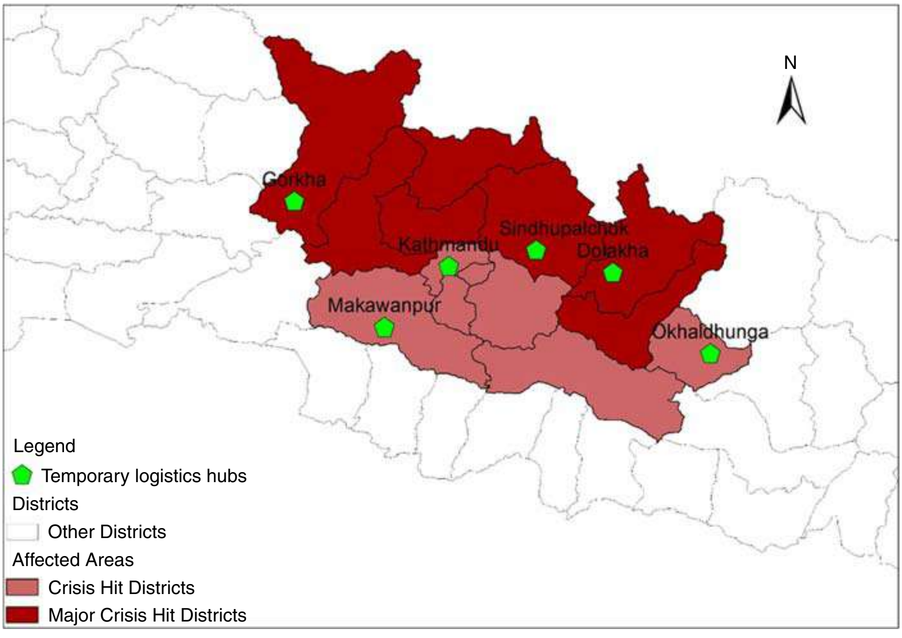

Figure 1.
Spatial location of temporary logistics hubs

S. no.	Attribute		Description of the attribute
1	Availability of open spaces	C_1	Determines whether there are open spaces available to establish TLHs
2	Accessibility via road	C_2	Refers to accessibility via road network, and determines the ease or difficulty in accessing the location by means of trucks, vans, etc.
3	Accessibility via air	C_3	Refers to accessibility issues via helicopters or planes
4	Security	C_4	Denotes the security of the warehouse and related facilitates around the selected location
5	Availability of necessary infrastructure	C_5	Refers to the availability of basic infrastructural facilities, like electricity, water supply, etc.
6	Availability of skilled manpower	C_6	Refers to the availability of the necessary manpower to support proper functioning of TLH in the candidate location
7	Disaster vulnerability of selected locations	C_7	Refers to the disaster vulnerability of the selected location alternative – for example, whether the location is susceptible to secondary disasters
8	Proximity to disaster-affected areas	C_8	Describes how close or far the selected location is from the affected areas in need of emergency relief

Table III.
Description of the attributes

Attributes	D_1	D_2	D_3	D_4	Aggregated fuzzy weight (AFW)	Defuzzified value of AFW	Normalized AFW
C_1	VH	VH	VH	H	(6.5, 9.25, 9.25, 10)	8.750	0.147
C_2	VH	VH	H	VH	(6.5, 9.25, 9.25, 10)	8.750	0.147
C_3	M	H	VH	VH	(5.25, 8, 8, 9.5)	7.687	0.129
C_4	H	M	H	H	(4.25, 6.5, 6.5, 9.5)	6.687	0.112
C_5	VH	H	VH	M	(5.25, 8, 8, 9.5)	7.687	0.129
C_6	M	VL	H	M	(2.25, 4.25, 4.25, 7.25)	4.500	0.076
C_7	H	VH	H	H	(5.5, 7.75, 7.75, 10)	7.750	0.130
C_8	VH	VH	M	H	(5.25, 8, 8, 9.5)	7.687	0.129

Table IV.
The importance weight of attributes

4.3 *Order of establishment of TLHs*

To determine the order of establishment, we used the six TLHs obtained from the first stage as alternatives and evaluated them further using the attributes selected in the second stage by applying the fuzzy multi-attribute group decision making method proposed in the third stage.

The decision opinions of decision makers in terms of fuzzy ratings for selected alternatives were obtained using the linguistic variables outlined in Table II. Table V shows the decision makers' evaluations and the aggregated fuzzy ratings computed for each alternative, as well as the respective criterion combination using Equation (18). The fuzzy ratings matrix in Table VI has been constructed using the aggregated ratings in Tables IV and V.

The normalized weight in Table IV and fuzzy ratings in Table VI were combined using Equation (19) to obtain the total fuzzy scores for each location. Table VII shows the resulting scores. The crisp values of the total fuzzy scores were obtained using the defuzzification Equation (20), shown in Table VII. Finally, the alternatives were ranked based on the defuzzified total scores and used to determine the order of establishment of TLHs (Table VII).

The results of the interviews with the decision makers in Table IV reveal the differences in their decision opinions. While three of the four decision makers revealed that the availability of open spaces is of very high importance, one decision maker placed comparatively lower importance on the same attribute. The decision opinions of different decision makers are heterogeneous in general – underscoring the importance of considering multiple decision makers in the evaluation process. The normalized aggregated fuzzy weight in Table IV shows that the "availability of open spaces" and "accessibility via roads"

Table V.
Decision makers' evaluation and fuzzy rating matrix

Attribute	Alternative	D1	D2	D3	D4	Aggregated fuzzy ratings
C_1	Dolakha	F	B.P and F	B.P and F	P	(7.5, 27.5, 42.5, 62.5)
	Gorkha	B.G and V.G	P	B.P and F	V.G	(35, 55, 67.5, 77.5)
	Kathmandu	G	V.P	P	G	(30, 45, 45, 65)
	Makwanpur	V.G	P	G	G	(50, 70, 70, 85)
	Okhaldhunga	F	P	B.F and G	B.P and F	(15, 35, 50, 70)
	Sindhupalchok	B.F and G	V.P	B.P and F	G	(22.5, 37.5, 52.5, 72.5)
C_2	Dolakha	B.F and G	F	B.P and F	F	(22.5, 42.5, 57.5, 77.5)
	Gorkha	B.G and V.G	G	F	G	(52.5, 72.5, 77.5, 92.5)
	Kathmandu	V.G	P	G	G	(50, 70, 70, 85)
	Makwanpur	B.G and V.G	G	G	G	(60, 80, 85, 100)
	Okhaldhunga	F	B.P and F	B.P and F	P	(7.5, 27.5, 42.5, 62.5)
	Sindhupalchok	F	F	B.P and F	G	(30, 50, 57.5, 77.5)
C_3	Dolakha	B.P and F	V.P	B.P and F	F	(7.5, 22.5, 37.5, 57.5)
	Gorkha	V.P	P	P	P	(0, 15, 15, 35)
	Kathmandu	V.G	G	G	G	(65, 85, 85, 100)
	Makwanpur	G	B.P and F	G	B.F and G	(37.5, 57.5, 72.5, 92.5)
	Okhaldhunga	F	P	B.P and F	P	(7.5, 27.5, 35, 55)
	Sindhupalchok	P	V.P	P	B.P and F	(0, 15, 22.5, 42.5)
C_4	Dolakha	G	F	B.P and F	F	(30, 50, 57.5, 77.5)
	Gorkha	F	G	B.F and G	G	(45, 65, 72.5, 92.5)
	Kathmandu	B.G and V.G	G	G	G	(60, 80, 85, 100)
	Makwanpur	B.F and G	G	B.F and G	G	(45, 65, 80, 100)
	Okhaldhunga	F	P	F	B.P and F	(15, 35, 42.5, 62.5)
	Sindhupalchok	F	B.P and F	B.P and F	G	(22.5, 42.5, 57.5, 77.5)
C_5	Dolakha	G	F	F	B.P and F	(30, 50, 57.5, 77.5)
	Gorkha	B.F and G	B.P and F	P	F	(15, 35, 50, 70)
	Kathmandu	B.G and V.G	G	B.F and G	B.F and G	(45, 65, 85, 100)
	Makwanpur	G	G	F	G	(52.5, 72.5, 72.5, 92.5)
	Okhaldhunga	F	P	B.P and F	B.P and F	(7.5, 27.5, 42.5, 62.5)
	Sindhupalchok	B.P and F	P	P	B.F and G	(7.5, 27.5, 42.5, 62.5)
C_6	Dolakha	G	P	B.P and F	P	(15, 35, 42.5, 62.5)
	Gorkha	B.F and G	B.P and F	P	B.P and F	(7.5, 27.5, 50, 70)
	Kathmandu	V.G	G	B.F and G	B.F and G	(50, 70, 85, 100)
	Makwanpur	G	B.P and F	B.P and F	B.F and G	(22.5, 42.5, 65, 85)
	Okhaldhunga	F	B.V.P and P	B.P and F	P	(7.5, 22.5, 35, 55)
	Sindhupalchok	B.P and F	P	P	B.F and G	(7.5, 27.5, 42.5, 62.5)
C_7	Dolakha	B.G and V.G	F	B.P and F	B.P and F	(22.5, 42.5, 62.5, 77.5)
	Gorkha	F	B.F and G	B.P and F	G	(30, 50, 65, 85)
	Kathmandu	B.G and V.G	G	F	F	(45, 65, 70, 85)
	Makwanpur	F	G	F	G	(45, 65, 65, 85)
	Okhaldhunga	F	B.V.P and P	F	B.P and F	(15, 30, 42.5, 62.5)
	Sindhupalchok	P	B.P and F	B.P and F	G	(15, 35, 50, 70)
C_8	Dolakha	B.G and V.G	F	B.P and F	B.P and F	(22.5, 42.5, 62.5, 77.5)
	Gorkha	G	B.F and G	F	B.G and V.G	(45, 65, 77.5, 92.5)
	Kathmandu	F	G	B.F and G	F	(37.5, 57.5, 65, 85)
	Makwanpur	P	G	F	B.F and G	(30, 50, 57.5, 77.5)
	Okhaldhunga	F	B.P and F	B.P and F	B.P and F	(7.5, 27.5, 50, 70)
	Sindhupalchok	B.G and V.G	B.P and F	F	V.G	(42.5, 62.5, 75, 85)

were perceived as highly important attributes, while the "availability of skilled labor" was deemed least important.

The order of establishment of TLHs can be determined with reference to the defuzzified total scores provided in Table VI. A higher value of a defuzzified total score means that the selected TLH performs better than its alternatives, and should thus be established first to achieve maximum effectiveness. Based on the decision opinions of four decision makers considered

Table VI.
Fuzzy rating matrix

Attributes	Dolakha	Gorkha	Kathmandu	Makwanpur	Okhaldhunga	Sindhupalchok
C_1	(7.5, 27.5, 42.5, 62.5)	(35, 55, 67.5, 77.5)	(30, 45, 45, 65)	(50, 70, 70, 85)	(15, 35, 50, 70)	(22.5, 37.5, 52.5, 72.5)
C_2	(22.5, 42.5, 57.5, 77.5)	(52.5, 72.5, 77.5, 92.5)	(50, 70, 70, 85)	(60, 80, 85, 100)	(7.5, 27.5, 42.5, 62.5)	(30, 50, 57.5, 77.5)
C_3	(7.5, 22.5, 37.5, 57.5)	(0, 15, 15, 35)	(65, 85, 85, 100)	(37.5, 57.5, 72.5, 92.5)	(7.5, 27.5, 35, 55)	(0, 15, 22.5, 42.5)
C_4	(30, 50, 57.5, 77.5)	(45, 65, 72.5, 92.5)	(60, 80, 85, 100)	(45, 65, 80, 100)	(15, 35, 42.5, 62.5)	(22.5, 42.5, 57.5, 77.5)
C_5	(30, 50, 57.5, 77.5)	(15, 35, 50, 70)	(45, 65, 85, 100)	(52.5, 72.5, 72.5, 92.5)	(7.5, 27.5, 42.5, 62.5)	(7.5, 27.5, 42.5, 62.5)
C_6	(15, 35, 42.5, 62.5)	(7.5, 27.5, 50, 70)	(50, 70, 85, 100)	(22.5, 42.5, 65, 85)	(7.5, 22.5, 35, 55)	(7.5, 27.5, 42.5, 62.5)
C_7	(22.5, 42.5, 62.5, 77.5)	(30, 50, 65, 85)	(45, 65, 70, 85)	(45, 65, 65, 85)	(15, 30, 42.5, 62.5)	(15, 35, 50, 70)
C_8	(22.5, 42.5, 62.5, 77.5)	(45, 65, 77.5, 92.5)	(37.5, 57.5, 65, 85)	(30, 50, 57.5, 77.5)	(7.5, 27.5, 50, 70)	(42.5, 62.5, 75, 85)

homogeneous, the final order of establishment should see the first TLH installed in Kathmandu, followed by Makwanpur, Gorkha, Dolakha, Sindhupalchok and finally Okhaldhunga. The spider chart in Figure 2 illustrates the performance of the selected TLHs over the selected attributes. As seen in Figure 2, the location alternative of Kathmandu performs the best among the six selected TLHs and, therefore, should be established first. While Kathmandu lags behind other alternatives in terms of open space availability, accessibility via roads and proximity to disaster-affected areas, it performs better overall.

In order to understand the importance of including multiple actors and their impact on the overall decision making process, we performed further calculations under different scenarios. Table VIII provides a comparison of the results in terms of variation in the order of establishment under three scenarios: single actor, multi-actor homogeneous and multi-actor heterogeneous. When the decision making process is conducted by only one decision maker, the order of establishment is as follows: Kathmandu, Makwanpur, Dolakha, Gorkha, Okhaldhunga and Sindhupalchok. In the homogenous multi-actor scenario, the order of establishment is Kathmandu, Makwanpur, Gorkha, Dolakha, Sindhupalchok and Okhaldhunga. Meanwhile, in a heterogeneous multi-actor scenario, the order is Kathmandu, Makwanpur, Gorkha, Sindhupalchok, Dolakha and Okhaldhunga. This highlights the

Table VII. Aggregated fuzzy number, defuzzified total score and order of establishment

Location alternatives	Aggregate fuzzy number	Defuzzified total score	Order of establishment
Kathmandu	(47.21, 66.48, 72.38, 88.76)	68.71	I
Makwanpur	(44.31, 64.31, 71.34, 89.87)	67.46	II
Gorkha	(30.16, 49.51, 60.14, 77.29)	54.27	III
Dolakha	(19.60, 38.96, 52.88, 71.58)	45.76	IV
Sindhupalchok	(19.23, 37.85, 50.46, 69.17)	44.18	V
Okhaldhunga	(10.42, 29.40, 43.04, 63.04)	36.48	VI

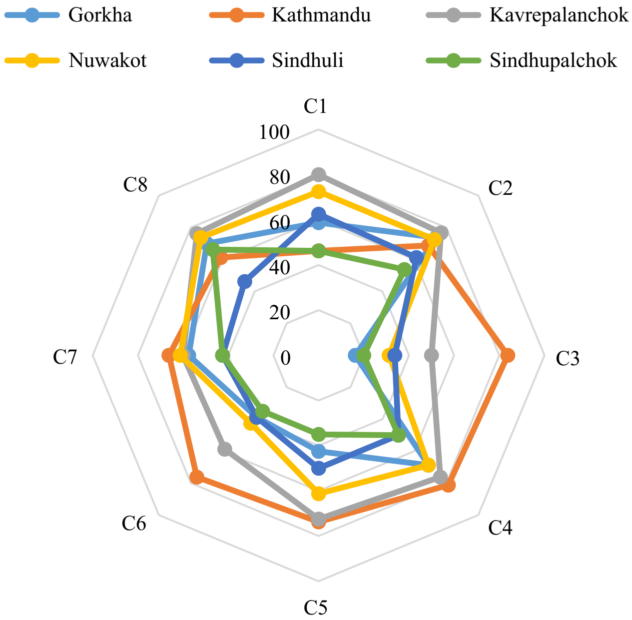

Figure 2. Performance of TLHs over all attributes

importance of considering multiple decision makers and their influence over the decision making process – as is the case in reality.

5. Conclusion

Recently, temporary facilities for disaster response have received growing attention from scholars and practitioners alike. However, location selection and ordering are immensely complex due to the lack of information, growing number of humanitarian responders and the need to evaluate subjective attributes during the chaotic disaster response period. This study has combined an optimization model with fuzzy multi-attribute group decision making to develop a methodology for determining the order of establishment of TLHs. This is a three-stage process: the multi-period optimization problem determines the number and spatial location of TLHs by minimizing the total unsatisfied demand; the fuzzy factor rating system calculates the importance weight of subjective attributes; and the fuzzy multi-attribute group decision making method ascertains the order of establishment of the selected TLHs by considering eight subjective attributes.

The proposed methodology was implemented using data obtained from The Nepal Earthquake (2015). Of the 11 candidate locations assumed to fulfill the dynamic demand over the entire planning horizon, the optimization model pinpointed 6 locations: Dolakha, Gorkha, Kathmandu, Makwanpur, Okhaldhunga and Sindhupalchok. Interviews with decision makers revealed the differences in their opinion regarding the prominence of different attributes. This difference in decision opinion was also observed when evaluating the performance of selected locations vs the attributes. Further analysis showed that the order of establishment varies significantly when the locations are evaluated under different scenarios. In this study, the order of establishment under the three scenarios of single actor, homogeneous multiple actors and heterogeneous multiple actors was found to differ considerably. This led us to conclude that it is essential to consider real-life scenarios when making decisions regarding TLHs.

This work contributes to the broader literature by developing a comprehensive methodology that considers both subjective and objective attributes, as well as the presence of multiple decision makers, in determining the location and order of establishment of TLHs. It also provides insights into the importance of incorporating different factors in addition to merely determining their numbers and spatial location into establishment decisions. This methodology offers valuable managerial insights for TLH establishment decision making after disasters when resources are limited and their effective utilization is particularly vital. The practical implication of involving multiple decision makers early in the decision making process allows synthesis of information from more than one decision maker during the information scarce response phase. Additionally, involvement of multiple decision makers also helps to develop a sense of ownership of the established hubs that can enable coordination and avoid complication between the growing numbers of humanitarian responders during the disaster response phase. The operational sustainability of the established TLHs is essentially important during the resource constrained response phase. The evaluation of TLH location alternatives based on the

	Order of establishment		
		Multi-actor	
Selected locations	Single actor	Homogeneous	Heterogeneous
Dolakha	III	IV	V
Gorkha	IV	III	III
Kathmandu	I	I	I
Makwanpur	II	II	II
Okhaldhunga	V	VI	VI
Sindhupalchok	VI	V	IV

Table VIII. Comparison of single and multiple actor scenarios eight selected qualitative attributes allows for ensuring operational sustainability of the established hubs. Based on the performance of TLH over the selected attributes, insightful suggestions can be made to strengthen the performance over the weaker attributes.

Moreover, the application of the proposed methodology is not limited to TLHs location and order selection. With appropriate modification, this methodology can be effectively applied to facilities such as medical centers and emergency shelters, as well as to other types of decision making during emergencies. Further studies can focus on several aspects, including the heterogeneity of decision makers, which would enable us to better approximate real-life scenarios, consider inclusion of parameters like time needed to serve demand point and accommodate the uncertain nature of the location problem.

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