MODELING TEMPORARY LOGISTICS HUB ESTABLISHMENT USING MULTI-CRITERIA DECISION MAKING APPROACH

***Rajali Maharjan*[1], *Shinya Hanaoka*[2]**
[1]*Department of International Development Engineering, Tokyo Institute of Technology, 2-12-1-14-12, Ookayama, Meguro, Tokyo, 152-8850, Japan*
[2]*Department of Transdisciplinary Science and Engineering, Tokyo Institute of Technology, 2-12-1-14-12, Ookayama, Meguro, Tokyo, 152-8850, Japan*

Abstract
Purpose
This study develops a new method that determines the location and the order of establishment of temporary logistics hubs (TLHs) taking account of multiple-objectives, multiple-attributes, and multiple-actors during disaster response. The research is motivated by the importance of TLHs and the complexity that surrounds its establishment.

Design/methodology/approach
A multi-period multi-objective mathematical model is developed to determine the location of the TLHs and a fuzzy simple additive weighing under the group decision-making (GDM) condition to determine the order of establishment of TLHs.

Findings
The optimization results provide useful managerial insights for decision-makers by considering the trade-off between two non-commensurable objectives. Determining the order of establishment helps to efficiently allocate mobile storage units when they limited in numbers. Use of fuzzy approach to evaluate subjective attributes eases the overall decision-making process.

Research limitations/implications
In this study, decision-makers are considered to be homogeneous, which might not reflect reality. This study does not consider the stochastic nature of relief demand and thus assumes demand to be known.

Practical implications
The outcomes of this study are valuable to decision-makers for relief distribution planning when there are multiple objectives, numerous decision-makers, and several attributes. The proposed fuzzy simple additive weighing approach under GDM is especially useful during emergency situation because of its ability to take account of vagueness and imprecision inherent in decision-making.

Originality/value
A new method is proposed and implemented to determine the location and the order of establishment of TLHs considering multi-objective, multi-attribute, and multi-actor nature of decision making during disaster response. To the best of the authors' knowledge, the multi-objective, multi-attribute, and multi-actor aspects of the TLH location problem have not thus far been considered simultaneously for one particular problem in humanitarian logistics.

Keywords: temporary logistics hub, multi-objective optimization, weighted-sum method, fuzzy simple additive weighing, group decision-making, facility location problem, humanitarian supply chain, emergency relief

Introduction

Disaster response is a critical task given the uncertainty and suddenness associated with disasters. The location of facilities, particularly distribution centers and warehouses play a significant role in ensuring the success of emergency humanitarian relief operations. While vulnerable countries should ideally prepare designated spaces for these facilities along with safety stockpiles in advance of any disaster occurring, the situation in reality is often different. The lack of advance preparedness in emerging countries necessitates for an appropriate, effective, and efficient response. Additionally, the unpredictability of disasters prevents authorities from determining an exact location for emergency facilities beforehand and given that permanent facilities alone may be insufficient, temporary emergency facilities become especially important in developing countries where disaster preparedness falls short.

Selecting where to locate temporary facilities and how to allocated limited quantities of mobile storage units that are used as temporary logistics hubs (TLHs) is an important task. Additionally, this can be complicated by the growing number of humanitarian actors, prevalence of multiple and often conflicting objectives, and inherent complexity and uncertainty of the situation. Moreover, current guidance suggests that within the humanitarian coordination architecture, decisions should be made by a group rather than by individuals (IASC, 2009, 2015). As the number of actors involved in disaster response operations has continued to grow, a complex network that often struggles to efficiently coordinate efforts has emerged (Balcik et al., 2010; Bharosa et al., 2010; Bealt et al., 2016). Therefore, it is important that the problem of temporary facility location incorporates the conflicting objectives, several attributes, and diverse opinion of multiple decision-makers.

Based on the foregoing, this study presents a comprehensive methodology to determine the number, location, and order of establishment of TLHs. A multi-period multi-objective optimization model is developed to determine the number and location of TLHs in the post-disaster stage and a fuzzy simple additive weighting system under group decision making (GDM) for determining the order of establishment of TLHs. The proposed approach allows us to take account of important factors like multiple conflicting objectives, multiple-attributes, and multiple-actors prevalent in disaster response activities. Furthermore, fuzzy approach is suitable for GDM problems under uncertainty because of the vagueness and imprecision inherent in decision-making during emergencies. With this context, this study proposes a comprehensive approach using multi-objective optimization, fuzzy simple additive weighing under GDM to determine the number, the location, and the order of establishment of TLHs. To our knowledge, this study is the first of its kind to use a multi-objective, multi-attribute, and multi-actor approach to determine the location and the order of establishment of TLHs during disaster response.

The remainder of this paper is organized as follows. In section 2, we review the relevant literature on the temporary facility location models used in humanitarian operations. In section 3, we describe the problem under consideration. Section 4 explains the methodology of the proposed approach. In section 5, we present the results of a numerical experiment based on the April 2015 Nepal earthquake. Finally, section 6 concludes.

Literature review

Recently temporary facility location problem has received growing attention. Afshar and Haghani (2012) model integrated logistics disaster operations by minimizing total weighted unsatisfied demand. Lin et al. (2012) proposed a two-phase heuristic approach to locate temporary depots and allocate covered demand by minimizing logistics and penalty costs. Khayal (2015) develops a network flow model for emergency response planning by minimizing logistics and penalty costs. Cavdur et al. (2016), develop a two-stage stochastic program for allocating temporary disaster response facilities in short-term disaster operations by minimizing the total distance travelled, unmet demand, and the cost of facilities. Finally, Stauffer et al. (2016), developed a model that minimizes total vehicular costs over the planning period to determine the location of temporary hubs for vehicles.

While the humanitarian code of conduct prioritizes minimizing victims' suffering, the budgetary limitations creates a trade-off situation highlighting multiple objectives as a distinguishing feature of humanitarian logistics operations. Kovacs and Spens (2007) states, the typical actors involved in disaster response operations include aid agencies, donors, governments, the military, logistics providers, and other non-governmental organizations which makes presence of multiple actors another distinctive feature of humanitarian logistics operations. Yet studies focusing on temporary facilities have failed to take account of multi-objective and multi-actor nature of temporary facility location and establishment ordering problems.

Moreover, the concept of order of establishment is almost non-existent in the current literature. When dealing with temporary facilities for disaster response, it is essential to consider resource constraint for establishing temporary facilities. A fuzzy multi-attribute approach may best suit the problem of determining the order of establishment of temporary facilities. The fuzzy simple additive weighing system under GDM developed by Chou et al. (2008) for facility location selection is an effective method for dealing with subjective/objective attributes.

Problem description
The problem under consideration is determining the location and the order of establishment of TLHs. Figure 1 shows the structure of a typical humanitarian supply chain and the positioning of TLHs within. In our study, a TLH is defined as a place designated for storing, sorting, consolidating, deconsolidating, and distributing emergency relief materials to disaster-affected areas in the short term. It thus acts as an intermediator between the central warehouse or relief supply points and areas in need and is often established after the disaster.

The supplies from permanent warehouses or entry points typically come in larger vehicles, which might be unable to access affected areas because of partial or complete damage to roads and bridges. In the absence of logistics hubs, the congestion created by larger vehicles using vulnerable road network may cause delivery times to increase significantly. In particular, the temporary nature of hubs is important in developing countries where infrastructure facilities are poor, resources for disaster response are limited and disaster preparedness usually falls short. Resource constraint necessitates effective allocation and utilization of resources during the immediate aftermath of the disaster. Determining the order of establishment of TLHs plays a key role in efficient allocation and thus effective utilization of mobile storage units which are used as the TLHs and are often limited in number immediately after the disaster.

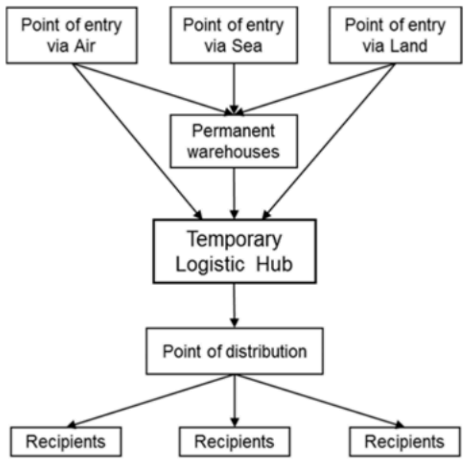

Figure 1: Structure of a humanitarian supply chain

Methodology
In the following section, we explain the methodology to determine the location and the order of establishment of TLHs using the concepts of multi-objective optimization, fuzzy set theory, simple additive weighing, and factor rating system under the group decision making (GDM) condition. The proposed method is modified version of fuzzy multi-attribute decision making approach developed by Chou et al. (2008).

Step 1: Determination of location alternatives

We propose a multi-period multi-objective TLH location model to determine the optimal number and location of TLHs. The proposed method allows us to accurately capture the changing levels of relief demand, supplies, and costs over the planning horizon. Each district or demand point has an associated demand for emergency relief materials. Along the discrete time horizon, demand from the affected zone changes in a known way related to changes in the number of affected people and recovery of affected people, as a result of which demand can either increase or decrease or be stagnant. The establishment of logistics hubs is required to meet the demand of affected people over the entire relief time horizon. The amount of emergency relief materials available in the TLHs can be either less than or equal to the capacity of TLHs but cannot exceed its capacity. The optimization problem minimizes total costs and total unsatisfied demand under dynamic demand, costs, and available units of emergency relief using weighted sum method resulting in the optimal number and location of TLHs.

The notations used in the mathematical model are as follows:
Sets, parameters and variables

T set of time periods
I set of supply points
J set of temporary logistic hubs (TLHs)
K set of affected area demand points
TC_{ijt} transportation cost of shipping one unit of the relief package from supply point *i* to TLH *j* in period *t* [USD per unit]
TC_{jkt} transportation cost of shipping one unit of relief package from TLH *j* to the affected area's demand point *k* in period *t* [USD per unit]
FC_j Fixed cost of opening a TLH in the candidate location [USD]
QS_{it} maximum available quantity of emergency relief materials at supply point *i* ∈ I in period *t* [kg]
QH_{jt} maximum available quantity of emergency relief materials at TLH *j* ∈ J in period *t* [kg]
d_{kt} demand of the affected area's demand point *k* in period *t* [kg]
n_{kt} number of TLHs allocated for demand point k in period *t*
M a very large number
r_{ijt} amount of emergency relief materials shipped from supply point *i* ∈ I to TLH *j* ∈ J in period *t* ∈ T
q_{jkt} amount of emergency relief materials shipped from TLH *j* ∈ J to the affected area's DP *k* ∈ K in period *t* ∈ T
y_j binary variable that equals 1 if the facility at *j* is selected as a TLH and 0 otherwise
y_{jkt} binary variable that equals 1 if TLH j serves demand point k in period *t* and 0 otherwise

The multi-objective optimization problem is formulated as follows:
Minimize,

$$Objective\ 1: O_1 = \sum_j FC_j y_j + \sum_i \sum_j \sum_t TC_{ijt} r_{ijt} + \sum_j \sum_k \sum_t TC_{jkt} q_{jkt} \quad (1)$$

$$Objective\ 2: O_2 = \sum_k \sum_t d_{kt} - \sum_j \sum_k \sum_t q_{jkt} \quad (2)$$

Constraints,

$$\sum_j \sum_k \sum_t q_{jkt} = \sum_i \sum_j \sum_t r_{ijt} \quad (3)$$

$$\sum_i \sum_j \sum_t r_{ijt} \leq \sum_i \sum_t QS_{it} \quad (4)$$

$$\sum_i \sum_j \sum_t r_{ijt} \leq \sum_j \sum_t QH_{jt} * y_j \quad (5)$$

$$\sum_j \sum_k \sum_t q_{jkt} \leq \sum_j \sum_t QH_{jt} * y_j \quad (6)$$

$$\sum_k \sum_t d_{kt} \geq \sum_j \sum_k \sum_t q_{jkt} \quad (7)$$

$$\sum_j \sum_t y_{jkt} \leq n_{kt} \ \ \forall k \quad (8)$$

$$y_{jkt} \leq y_j \qquad \forall j \quad (9)$$

$$\sum_i \sum_j \sum_t r_{ijt} \leq M * \sum_j y_j \quad (10)$$

$$\sum_j \sum_k \sum_t q_{jkt} \leq M * \sum_j y_j \quad (11)$$

$$r_{ijt} \geq 0 \ \ \forall i, j, \text{t} \quad (12)$$

$$q_{jkt} \geq 0 \ \ \forall j, k, t \quad (13)$$

$$y_j = \{0,1\} \ \forall j \quad (14)$$

$$y_{jkt} = \{0,1\} \ \forall j \quad (15)$$

The objective function (1) minimizes total costs, which includes the fixed cost of opening a TLH, transportation cost from the supply point to the TLH, and transportation cost from the TLH to the affected area's demand points. Objective function (2) minimizes total unsatisfied demand. Constraint (3) ensures that the flow of emergency relief materials from the supply points to TLHs should be equal to the flow from the TLHs to the affected area's demand points. Constraints (4) – (6) are the availability constraints. Constraint (4) 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 (5) and (6) ensure that the quantity of emergency relief materials moved from the supply points to the TLHs and from TLHs to affected area's demand points should be less than or equal to the maximum available quantity of emergency relief materials in the TLHs in each period. Constraint (7) ensures that the quantity of emergency relief delivered for each demand point does not exceed its demand. Constraint (8) enforces multi-sourcing, ensuring that each demand point is served by a pre-specified number of TLHs.

Constraint (9) ensures that a demand point is served by TLH only if TLH is open. Constraints (10) and (11) oblige the flow of emergency relief to open “hubs” only. Constraints (12) – (15) express the nature of the decision variables used in the model.

Step 2: Selection of attributes

Several attributes play significant role in determining the order of establishment of TLHs. The term attribute is used to refer to only subjective attributes in this study. The attributes can be selected based on criteria like: socio-economic situation of the country, geo-climatic situation, literature review, and review of lessons learnt reports of past disasters. The selected attributes should be able to ensure sound operability of the established TLHs at the minimum.

Step 3: Selection of decision-makers

Under the GDM scenario, multiple decision-makers can be chosen. The choice of decision-maker also varies 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 four situations: (1) when the decision-makers are homogeneous (1.1) their decision opinions are homogeneous; (1.2) their decision opinions are heterogeneous; (2) when the decision-makers are heterogeneous (2.1) their decision opinions are homogeneous; and (2.2) their decision opinions are heterogeneous.

Step 4: Determining the degree of importance of decision makers.
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 to be a homogeneous group. Otherwise the group is deemed heterogeneous.

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

Step 5: Collecting decision opinions and computing the aggregated fuzzy weight of individual attributes.

Introduce linguistic variables (Table 1) for decision-makers to assess attributes importance. Subsequently, compute the aggregated fuzzy rating of the individual attributes. Let $\widetilde{W}_{jt} = (a_{jt}, b_{jt}, c_{jt}, d_{jt})$, *j = 1, 2, …., n; t = 1, 2, ….,k,* be the linguistic rating given to attributes $C_1, C_2, \ldots, C_n$ by decision-maker D_t. The aggregated fuzzy rating, $\widetilde{W}_j = (a_j, b_j, c_j, d_j)$, of attribute C_j assessed by the committee of *k* decision-makers is defined as

$$\widetilde{W}_j = (I_1 \otimes \widetilde{W}_{j1}) \oplus (I_2 \otimes \widetilde{W}_{j2}) \oplus \ldots \oplus (I_k \otimes \widetilde{W}_{jk}), \quad (16)$$

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

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)

Table 1. Linguistic variables and fuzzy numbers

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

Table 2. Linguistic variables and fuzzy numbers for ratings

Step 6: Computing the importance weight of attributes.
T
o 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 $\widetilde{W}_j$, denoted as $d(\widetilde{W}_j)$ is therefore given by $d(\widetilde{W}_j) = \frac{1}{k}(a_j + b_j + c_j + d_j)$ (17)

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

$$W_j = \frac{d(\widetilde{W}_j)}{\sum_{j=1}^{n} d(\widetilde{W}_j)}, \quad (18)$$

where $\sum_{j=1}^{n} W_j = 1$. The weight vector W = $[W_1, W_2, \ldots, W_n]$ is therefore formed.
This crisp values of the normalized weight of the attributes C_j can therefore be used as the importance weight of the attributes.

Step 7: Obtain the decision-opinion of decision-makers using fuzzy ratings to assess each alternative with respect to individual attributes and obtain aggregated fuzzy ratings.

Using the linguistic variables (Table 2) for decision-makers to assess fuzzy ratings of alternatives with respect to individual attributes obtain the decision-opinion and pool them to obtain the aggregated fuzzy ratings. Let $\tilde{x}_{ijt}$= $(o_{ijt}, p_{ijt}, q_{ijt}, r_{ijt})$, *i* = 1, 2, . . . , *m; j* = 1, 2, . . . , *n; t* = 1, 2, . . . , *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

$$\tilde{x}_{ij} = (I_1 \otimes \tilde{x}_{ij1}) \oplus (I_2 \otimes \tilde{x}_{ij2}) \oplus \ldots \oplus (I_k \otimes \tilde{x}_{ijk}), \quad (19)$$

which can subsequently be represented and computed as,
$\tilde{x}_{ij}= (o_{ij}, p_{ij}, q_{ij}, r_{ij})$, *i* = 1, 2, . . . , *m*, *j* = 1, 2, . . . , *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 8: Construct a fuzzy rating matrix based on fuzzy ratings.
The fuzzy rating matrix $\widetilde{M}$ can be concisely expressed in the matrix format

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

where $\tilde{x}_{ij}$, $\forall i, j$ is the aggregated fuzzy rating of alternative A_i with respect to attribute C_j.
Step 9: Derive the total fuzzy scores for individual alternative by multiplying the fuzzy rating matrix by their respective weight vectors.

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

$$\tilde{F} = \widetilde{M} \otimes W^T = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdot & \cdot & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \vdots & \vdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ . & . & \cdot & \cdot & . \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdot & \cdot & \tilde{x}_{mn} \end{bmatrix} \otimes \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ . \\ W_n \end{bmatrix} = \begin{bmatrix} \tilde{x}_{11} \otimes W_1 \oplus \tilde{x}_{12} \otimes W_2 \oplus \cdots \oplus \tilde{x}_{1n} \otimes W_n \\ \tilde{x}_{21} \otimes W_1 \oplus \tilde{x}_{22} \otimes W_2 \oplus \cdots \oplus \tilde{x}_{2n} \otimes W_n \\ \cdot \\ \vdots \\ \tilde{x}_{m1} \otimes W_1 \oplus \tilde{x}_{m2} \otimes W_2 \oplus \cdots \oplus \tilde{x}_{mn} \otimes W_n \end{bmatrix} = \begin{bmatrix} \tilde{f}_1 \\ \tilde{f}_1 \\ \cdot \\ \vdots \\ \tilde{f}_m \end{bmatrix} =$$

$[\tilde{f}_i]_{m*1}$, where $\tilde{f}_i = (s_i, t_i, u_i, v_i)$. (20)
Step 10: Compute the crisp values using a defuzzification method and finally, determine the order of establishment of TLHs.
Defuzzify the fuzzy scores $\tilde{f}_1, \tilde{f}_2, \ldots, \tilde{f}_m$ by using signed distance method. The following defuzzification equation is used to determine the crisp total scores of individual locations.

$$d(\tilde{f}_i) = \frac{1}{4}(s_i + t_i + u_i + v_i) \qquad i = 1, 2, \ldots, m \quad (21)$$

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

Step 11: Finally, rank the location alternatives based on the crisp values to determine the order of establishment of TLHs. The location alternatives with larger crisp values should be established first followed by the location alternatives with lower values.

Numerical example
To support the usefulness of the proposed methodology for selecting the number, location and the order of establishment of TLHs, numerical experiment was performed using disaster data from April 2015 Nepal earthquake.

Step 1: To determine the optimal number and location of TLHs, we consider seven supply points, eleven candidate TLHs, and 13 demand points. The optimal solution is achieved by minimizing total cost and total unsatisfied demand over the entire planning horizon. An operational horizon of five weeks is considered with each period lasting for one week. We considered a single package relief delivery system. A single emergency relief package was assumed to weigh 10 kg and include essential items such as meals, a basic medical kit, blankets, baby supplies, and clothing. We assumed that a single emergency relief package was sufficient to sustain an individual for a week. The demand, cost, and the available units of relief supplies are assumed to be dynamic. The model was coded in Lingo 17.0 Optimization modeling software. All the experiments were run on a personal computer with an Intel (R) Core (TM) i3-3220 CPU (3.30 GHz) and 8 GB of RAM. All the test problems were computed in under 10 minutes.

The model results in a total of eight optimal TLHs with locations in Gorkha, Kathmandu, Kavrepalanchok, Makwanpur, Nuwakot, Ramechhap, Sindhuli, and Sindhupalchok. The eight selected TLHs result in the minimum value of both objectives over the entire planning horizon.

Step 2: Eight attributes were identified via a combination of review of literature on facility location problem in humanitarian operations and lessons learnt reports published by different entities. The eight attributes are: availability of open spaces (C_1); Transportation accessibility via Road (C_2); Transportation accessibility via Air (C_3); Level of safety (C_4); Availability of skilled manpower (C_5); Availability of necessary infrastructure (C_6); Disaster vulnerability of selected locations (C_7); and Proximity to disaster affected areas (C_8).

Step 3: 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.

***Step* 4**: The decision-makers were assumed to be homogeneous hence the degree of importance is equal for all the decision-makers.

***Step* 5**: Table 3 shows the decision-opinion of four decision makers using the linguistic weighing variables. The aggregated fuzzy weight of individual attribute is computed by using equation (16) with reference to fuzzy numbers corresponding to each linguistic variables (Table 1).

Step 6: The importance weight of the attributes is calculated by defuzzifying the fuzzy numbers using signed distance approach represented by equation (17) and the normalized weight is calculated using equation (18). The crisp values after defuzzification and the normalized weight is shown in Table 3.

Attributes	D1	D2	D3	D4	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	M	VL	H	M	(2.25,4.25,4.25, 7.25)	4.500	0.076
C_6	VH	H	VH	M	(5.25,8,8, 9.5)	7.687	0.129
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 3: The importance weight of attributes

Step 7: The decision-opinion of decision-makers in terms of fuzzy rating of all eight alternatives were obtained using the linguistic variables in Table 2. The Table 4 shows the aggregated fuzzy rating computed for each alternative criterion combination obtained using equation (19).

Selected locations	Aggregate fuzzy number	Defuzzified total score	Order of establishment
Gorkha	(29.75, 49.11, 60.14, 77.29)	54.07	5
Kathmandu	(47.48, 66.75, 72.38, 88.76)	68.84	2
Kavrepalanchok	(45.47, 65.47, 73.79, 91.67)	69.10	1
Makwanpur	(42.70, 62.70, 70.94, 89.47)	66.45	3
Nuwakot	(35.28, 55.28, 66.50, 85.85)	60.73	4
Ramechhap	(24.88, 44.24, 53.76, 73.76)	49.16	6
Sindhuli	(24, 42.71, 54.30, 72.92)	48.48	7
Sindhupalchok	(19.23,37.85,50.46, 69.17)	44.18	8

Table 4: Decision-makers evaluation and fuzzy rating matrix

Step 8: With the aggregated ratings (Tables 3 and 4) construct the fuzzy rating matrix Table 5.

Attributes	Gorkha	Kathmandu	Kavrepalanchok	Makwanpur	Nuwakot	Ramechhap	Sindhuli	Sindhupalchok
C1	(35,55,67.5, 77.5)	(30,45,45, 65)	(57.5,77.5,85, 100)	(50,70,70, 85)	(52.5,72.5,72.5, 92.5)	(37.5,57.5,57.5, 77.5)	(37.5,57.5,70, 85)	(22.5,37.5,52.5, 72.5)
C2	(52.5,72.5,77.5, 92.5)	(50,70,70, 85)	(52.5,72.5,85, 100)	(60,80,85, 100)	(45,65,80, 100)	(22.5,42.5,72.5, 92.5)	(37.5,57.5,65, 85)	(30,50,57.5, 77.5)
C3	(0,15,15, 35)	(65,85,85, 100)	(30,50,50, 70)	(37.5,57.5,72.5, 92.5)	(0,20,42.5, 62.5)	(22.5,42.5,57.5, 77.5)	(15,30,35, 55)	(0,15,22.5, 42.5)
C4	(45,65,72.5, 92.5)	(60,80,85, 100)	(52.5,72.5,80, 100)	(45,65,80, 100)	(45,65,72.5, 92.5)	(45,65,65, 85)	(22.5,42.5,57.5, 77.5)	(22.5,42.5,57.5, 77.5)
C5	(15,35,50, 70)	(45,65,85, 100)	(52.5,72.5,72.5, 92.5)	(52.5,72.5,72.5, 92.5)	(30,50,72.5, 92.5)	(30,50,57.5, 77.5)	(22.5,42.5,57.5, 77.5)	(7.5,27.5,42.5, 62.5)
C6	(7.5,27.5,50, 70)	(50,70,85, 100)	(30,50,70, 85)	(22.5,42.5,65, 85)	(15,35,50, 70)	(7.5,22.5,27.5, 47.5)	(15,35,42.5, 62.5)	(7.5,27.5,42.5, 62.5)
C7	(30,50,65, 85)	(45,65,70, 85)	(37.5,57.5,65, 85)	(45,65,65, 85)	(37.5,57.5,65, 85)	(7.5,27.5,42.5, 62.5)	(15,35,50, 70)	(15,35,50, 70)
C8	(45,65,77.5, 92.5)	(37.5,57.5,65, 85)	(52.5,72.5,80, 100)	(30,50,57.5, 77.5)	(52.5,72.5,77.5, 92.5)	(30,50,50, 70)	(22.5,37.5,55, 70)	(42.5,62.5,75, 85)

Table 5: Aggregated fuzzy number and order of establishment

Step 9: Combine the normalized weight in Tables 3 and fuzzy ratings in Table 5 using equation (20) to obtain total fuzzy scores for each location. Table 5 shows the resulting scores.

Step 10: Obtain the crisp values of the total fuzzy scores using the defuzzification equation (21), shown in Table 5.

Step 11: Rank the alternatives based on the defuzzified total scores to determine the order of establishment of TLHs (Table 5).

Conclusion

Deciding on the best location and the order of establishment of TLHs to aid humanitarian relief distribution often involves more than one decision-maker, numerous attributes, and the trade-off between multiple objectives. Although, several studies have addressed the problem of determining the location of temporary facilities using optimization approach they have failed to address problems that may arise due to multiple objectives, numerous decision-makers, and resource limitation while establishing those facilities. On the other hand, several other studies have used multi-attribute decision making approach to determine the location of facilities with subjective/objective attributes they simply assume, the location alternatives are already there. In this study, we developed new approach that includes a mathematical model to determine the optimal location for TLHs by using a multi-objective optimization model with dynamic demand, cost, and capacities and a fuzzy simple additive weighing under GDM to determine the order of establishment of TLHs by evaluating various subjective attributes.

The model proposed herein was implemented using data obtained from the Nepal earthquake in 2015. The results of the optimization model accounts for the trade-off relationship between minimizing total costs and unsatisfied demand. Emphasizing on minimizing costs results in decreased demand satisfaction whereas emphasizing on minimizing unsatisfied demand leads to increased cost. The results of the questionnaire with humanitarian organizations show the heterogeneous nature of decision opinions while evaluating location alternatives with respect to subjective attributes highlighting the importance of including multiple decision makers in TLH location problem.

The outcomes of this study are valuable to decision-makers for relief distribution planning when there are non-commensurable objectives, multiple decision-makers, and various subjective attributes. The proposed fuzzy simple additive weighing approach under GDM is especially useful for decision-making during emergency situation because of its ability to take account of vagueness and imprecision. Finally, the practical implications of involving multiple decision-makers early in the location selection process might help to develop a sense of ownership that may aid in enhancing coordination efforts.

However, the model proposed in this study assumes all decision-makers have equal importance, which might not hold true in real-world disaster operations. Developing a method to determine the relative importance of decision-makers and incorporating it into the model is thus a possible extension of the model. Another possible extension would be to consider stochastic nature of relief demand.

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