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Multi-attribute Group Decision-Making for Emergency Evacuation with Storage at Nodes in Fuzzy Environment

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***Abstract*: Emergency evacuation has become of significant importance for emergency management in facing natural and human-made disasters. Decision-making during emergency evacuation is a prominent research area attracting more and more scientists. A crucial issue in emergency decision-making is fuzziness and uncertainty inherent in the process of decision-making. In addition, the process of decision-making is becoming more and more complicated because of the variety of aspects to consider. In this regard, this paper proposes an algorithm for emergency evacuation decision-making in fuzzy intuitionistic environment regarding two cases: when attribute weights are known in advance and when they are unknown. To transport the maximum number of aggrieved from the dangerous area to the safe destination, a dynamic flow model with transit arc capacities is constructed. The intermediate nodes in the network have limited capacities and can store the flow in order for the flow to be maximized. Uncertain experts' evaluations and high level of hesitance are incorporated into the decision-making process in the form of fuzzy intuitionistic numbers. Multi-attribute group decision-making is used to rank the intermediate shelters to evacuate the maximum possible number of aggrieved. In the method, experts have different weights for different attributes, which allows considering the degree of experts' competence for different attributes. A case study is conducted to illustrate evacuation of the maximum number of aggrieved with intermediate location at nodes with limited capacities in order to transport evacuees to the safe destination based on modified fuzzy intuitionistic TOPSIS.**

Keywords: Multi-attribute group decision making, intuitionistic fuzzy sets, TOPSIS.

I. Introduction

Throughout the world history, disasters and hazard events have spontaneously occurred and caused severe damage to life, property and society. Therefore, countries all over the world pay great attention to emergency. Hazard events are divided into natural, man-made and technological [1].

In recent years, the increasing number of extreme weather and natural disasters such as wildfires, hurricanes, earthquakes, tsunamis, and floods, has posed devastating threats to human life and social stability [2]. Among recent disasters [3] there were Wenchuan earthquakes in China in 2008 [4], Australia's catastrophic 2019/20 bushfires [5], Hurricane Sandy (October 2012) in the United States of America [6], 2011 Tohoku Earthquake Tsunami in Japan [7], 2023 earthquake in Turkey and Syria. Human-made disasters and accidents such as chemical accidents, terrorist attacks, nuclear weapons have led to significant human casualties and property losses as well [8]. Emergency evacuation has become the useful tool for emergency management in tackling these natural and human-made disasters.

The process of Emergency evacuation consists of quick and safe transportation of occupants out of endangered areas towards safe destinations [9-10]. Therefore, emergency evacuation is a holistic process, that incorporates monitoring and forewarning in the *pre-evacuation period*, evacuation planning and optimization, traffic management and logistics organization, etc. in the *intermediate stage*, and tackling the incomplete activities and restoration of the key resources in the post-emergency phase [11-14].

Emergency decision-making is one of the most important parts of decision theory. Owing to complex environment, lack of information about alternatives, it is difficult to give the exact evaluations of attributes. Moreover, experts often express hesitation and uncertainty while making decisions. In this regard, many valuable tools have been developed to simulate uncertainty while decision-making. Fuzzy sets proposed by L. Zade [15] indicated an expert's uncertainty in the form of a membership function, which shows the degree of belonginess of the element to the set. Later, various extensions of fuzzy sets were proposed which represent various degrees of experts' doubts about the specific value of membership degree. The following are representatives: type-2 fuzzy sets, fuzzy multisets, intuitionistic fuzzy sets, intuitionistic soft fuzzy sets, linguistic arguments, hesitant fuzzy sets. Intuitionistic fuzzy set consists of membership degree of an element to the set, non-membership degree and degree of hesitation [16]. Type-2 fuzzy set presents the membership of a given element as a fuzzy set. Type-*n* fuzzy set generalizes type-2 fuzzy set allowing the membership to be type- n-1 fuzzy set. In fuzzy multiset, the elements can be repeated more than once. Hesitant fuzzy set appears when a decision-maker has some possible values of attributes and is not sure what to choose so that using a set of possible membership degrees to assess the attribute [17]. In this paper, experts' evaluation will be presented as fuzzy intuitionistic numbers in order to rank the shelters for evacuation.

Multi-attribute decision-making [18] is prominent area of studies which incorporates various techniques to provide reasonable decision-making process by considering multiple and often conflicting attributes through a structured framework [19]. MADM is conventionally divided into following groups [20]:

1. Multi-attribute utility and value functions. These methods enable finding the value for the decision maker's preferences by utility functions. Based on this, all criteria are transformed into a common dimensionless scale [21]. Among these methods are multi-attribute utility theory (MAUT) and multi-attribute value theory (MAVT).

2. Pairwise comparisons. Pairs of attributes are compared according to their importance according to a given scale. This technique is useful when utility functions cannot be defined utility functions. Conventional approaches include analytical network process (ANP), analytical hierarchy process (AHP) etc. Despite its simplicity, AHP has some drawbacks such as the upper bound on the number of simultaneously considered alternatives [22].

3. Outranking approaches. This method is based on the assumption that one alternative may dominate another one with some degree instead of a single optimal solution [23]. ELECTRE (Elimination et choix traduisant la realité), PROMETHEE (preference ranking organization method for enrichment of evaluations) methods constitute the following group. There is no need to normalize the data or to find compensation between criteria according to these methods [24]. In this regard, they can be effectively used in such cases when it is difficult to aggregate attribute scales or measurement scales differ [21].

4. Methods tackling distances to ideal points. The alternatives are ranked according to the nearest distance from the ideal point and farthest distance to the worst point, which means that there are two hypothetical solutions (the best and the worst) [25]. Well-known methods include TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), CP (Compromise programming) and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje). The main advantage of the method is the opportunity to consider a non-limited number of alternatives and criteria.

5. Other methods. Integration of different methods, which leads to hybrid approaches. Recent advances include integration of fuzzy logic and multi-attribute decision-making methods (TOPSIS, ELECTREE, AHP) [26-29].

Multiple and conflicting objectives inherent in decision-making along with ambiguity and uncertainty make decision-making problems complex and difficult [30]. Multi-attribute group decision making is widely used in decision theory since the single experts cannot provide the true evaluations of each attribute. The tasks of real-life emergency decision-making are becoming complex and require much specific knowledge. Therefore, the experience of multiple experts is needed to make reasonable decisions. Experts' weights are often considered to be equal [30-31] or given beforehand [32-33], which can lead to the incorrect results. Due to various parameters incorporated into the decision-making process, experts should evaluate various attributes using different weights [34].

In TOPSIS, experts evaluate the alternatives based on the values of closeness coefficients. These values are defined based on positive and negative ideal solutions. The best alternative is considered to be the nearest to the positive ideal alternative and the farthest from the negative ideal alternative. Authors [35] applied fuzzy sets and their extensions and its extensions to handle uncertainty while making decisions based on TOPSIS. Authors [36-38] considered TOPSIS for emergency decision-making.

The main contribution of this study is a fuzzy maximum lexicographic dynamic flow algorithm based on the multiple attribute group decision making method. The difference of the method from existing that it allows us to rank the terminals during evacuation based on TOPSIS in intuitionistic fuzzy setting.

The rest of the paper is organized as follows. In Section 2, we observe basic concepts and definitions of intuitionistic fuzzy sets. The emergency evacuation environment is given in the Section 3. Section 4 observes a case study of the proposed method. Section 5 the method based on the linear combinations of spreads to handle triangular fuzzy numbers. observes Finally, section 6 concludes the paper and gives topics for future research.

II. Basic concepts and Definitions of Intuitionistic Fuzzy Sets

Fuzzy sets were introduced by L. Zade in order to describe inherent in reasoning and evaluations uncertainty. Fuzzy sets handle membership of an element to a set to indicate the grades of uncertainty. Intuitionistic fuzzy sets as a generalization of fuzzy sets were proposed by Atanassov in 1986 [16]. In intuitionistic fuzzy set, there are membership function and non-membership function which show the hesitance of a decision-maker. In addition, there is an intuitionistic index that indicates the level of expert's uncertainty.

Definition 1. Let $X \neq 0$ be a reference set. An intuitionistic fuzzy set $\tilde{A}$ is defined as:

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x), \nu_{\tilde{A}}(x)); x \in X\}, \quad (1)$$

where $\mu_{\tilde{A}}(x): X \to [0,1]$ and $\nu_{\tilde{A}}(x): X \to [0,1]$ satisfy the condition $0 \leq \mu_{\tilde{A}}(x) \leq 1$, for each $x \in X$.

An intuitionistic index $\pi_{\tilde{A}}(x)$, $0 \leq \pi_{\tilde{A}}(x) \leq 1$, that indicates the degree of uncertainty is:

$$\pi_{\tilde{A}}(x) = 1 - \mu_{\tilde{A}}(x) - \nu_{\tilde{A}}(x). \quad (2)$$

Let $\tilde{A} = (\mu_{\tilde{A}}, \nu_{\tilde{A}})$ and $\tilde{B} = (\mu_{\tilde{B}}, \nu_{\tilde{B}})$ be IFS of the set X; then the basic operations with IFS are defined as follows:

$$\tilde{A}\oplus\tilde{B} = (\mu_{\tilde{A}}(x) + \mu_{\tilde{B}}(x) - \mu_{\tilde{A}}(x)\mu_{\tilde{B}}(x), \nu_{\tilde{A}}(x) \times \nu_{\tilde{B}}(x), x \in X). \quad (3)$$

$$k\tilde{A} = (1 - (1 - \mu_{\tilde{A}}(x)^k, \nu_{\tilde{A}}(x)^k, x \in X, k > 0. \quad (4)$$

To compare IFS the score function is used [26]. Let $s(\tilde{A}) = \mu_{\tilde{A}} - \nu_{\tilde{A}}, s(\tilde{A}) \in [-1,1]$ be the score if the IFS $s(\tilde{A})$. If the scores are equal, the accuracy functions are implemented, where $f(\tilde{A}) = \mu_{\tilde{A}} + \nu_{\tilde{A}}$, $f(\tilde{A}) \in [0,1]$.

Definition 2. Let $\tilde{A} = (\mu_{\tilde{A}}, \nu_{\tilde{A}})$ and $\tilde{B} = (\mu_{\tilde{B}}, \nu_{\tilde{B}})$ be two IFVs.

If $s(\tilde{A}) < s(\tilde{B})$, then $\tilde{A}$ is smaller than $\tilde{B}$, denoted by $\tilde{A} < \tilde{B}$;

If $s(\tilde{A}) = s(\tilde{B})$, and

1) if $f(\tilde{A}) < f(\tilde{B})$, then $\tilde{A}$ is smaller than $\tilde{B}$, denoted by $\tilde{A} < \tilde{B}$;

2) if $(\tilde{A}) = f(\tilde{B})$, then $\tilde{A}$ and $\tilde{B}$ represent the same information, denoted by $\tilde{A} = \tilde{B}$.

The distance [26] between two IFS $\tilde{A} = (\mu_{\tilde{A}}, \nu_{\tilde{A}})$ and $\tilde{B} = (\mu_{\tilde{B}}, \nu_{\tilde{B}})$ is defined as follows:

$$d(\tilde{A}, \tilde{B}) = \frac{1}{2}(|\mu_{\tilde{A}} - \mu_{\tilde{B}}| + |\nu_{\tilde{A}} - \nu_{\tilde{B}}|). \quad (5)$$

The task of determining the maximum number of evacuees flow the dangerous area to the shelter with people' s storage at intermediate destinations is given as a model (6)-(8). Eq. (8) gives the upper bounds of flow for each node at each time period. The model given by Eqs. (6)-(8) gives the ranked set of intermediate nodes with storage to transfer the aggrieved to the safe destination $x_1 \subseteq x_2 \subseteq \cdots x_m$, where x_1 has the highest priority and x_m – the lowest one. This ranked set will be found by multiple attribute intuitionistic fuzzy group decision making algorithm based on TOPSIS. Each node has node capacity $\tilde{x}(\theta)$. Each arc has a time-depended assigned fuzzy arc capacity $\tilde{u}_{ij}(\theta)$ and traversal time $\tau_{ji}(\theta)$.

$$val(\tilde{\gamma}, T) \to max = \sum_{\theta=0}^{T} \sum_{x_j \in \Gamma(s)} \tilde{\xi}_{sj}(\theta) \geq \sum_{\theta=\tau_{st}}^{T} \sum_{x_k \in \Gamma^{-1}(t)} \tilde{\xi}_{kt}(\theta + \tau_{st}) \quad (6)$$

Subject to: $\sum_{\theta=\tau_{ij}}^{\vartheta} \sum_{x_k \in \Gamma^{-1}(i)} \tilde{\xi}_{ki}(\theta - \tau_{ij}) - \sum_{\theta=0}^{\vartheta} \sum_{x_j \in \Gamma^{1}(i)} \tilde{\xi}_{ij}(\theta) \geq \tilde{0}, \forall (x_i, x_j) \neq \{s, t\}, \vartheta \in T$, (7)

$$0 \leq \tilde{\xi}_{ij}(\vartheta) \leq \tilde{u}_{ij}(\vartheta), \forall (x_i, x_j) \in \tilde{A}, \in T. \quad (8)$$

The original definition of a fuzzy graph [24] was based on the concept of a fuzzy relationship between vertices [25]. The concept of complementing a fuzzy graph and some operations on fuzzy graphs were considered in [26, 27]. The concepts of an intuitionistic fuzzy relation and an intuitionistic fuzzy graph were considered in the papers [28, 29]. The concepts of a dominating set, and a base set as invariant of intuitionistic fuzzy graph were introduced in the papers [30 - 34].

III. Emergency Evacuation Environment

A. MAGDM Algorithm in Intuitionistic Environment for Ranking the Shelters for Evacuation

Let us consider a multi-attribute group decision-making problem in intuitionistic environment for ranking the shelters for evacuation. In group decision-making, several experts are needed to evaluate the alternatives in order to get reasonable decisions. Let $\{C_1, C_2, \dots C_t\}$ be the set of experts, $\{A_1, A_2, \dots A_m\}$ – the set of alternatives, $\{B_1, B, \dots B_n\}$ be the set of attributes.

Present the Algorithm to find the relative order of alternatives in intuitionistic fuzzy conditions as a MAGDM problem when the attribute weights are completely unknown [26, 36].

Step 1. Present experts' evaluation in the form of decision matrices $D^k = (\alpha_{ij}^k)_{m\times n}$, where $(\alpha_{ij}^k) = (\mu_{ij}^k, \nu_{ij}^k)$.

Step 2. Compose the positive ideal decision matrix $D^+ = (\alpha_{ij}^+)_{m\times n}$ and the negative ideal decision matrices $D^d = (\alpha_{ij}^d)_{m\times n}$ and $D^u = (\alpha_{ij}^u)_{m\times n}$, where $\alpha_{ij}^+ = (\sum_{k=1}^t \alpha_{ij}^k)/t, i = 1,2,..,n, k = 1,2,..t, \alpha_{ij}^d = \min_{1\leq k\leq t}\{\alpha_{ij}^{(k)} | \alpha_{ij}^{(k)} \leq \alpha_{ij}^+\}$, $\alpha_{ij}^u = \max_{1\leq k\leq t}\{\alpha_{ij}^{(k)} | \alpha_{ij}^{(k)} \geq \alpha_{ij}^+\}$.

Step 3. Compose the collective decision matrix $D = (\alpha_{ij})_{m\times n}$ according to the values of closeness coefficients applying intuitionistic fuzzy weighted averaging operator.

To do it, firstly, find the distances between the expert's evaluation α_{ij}^k and positive ideal α_{ij}^+ along with the negative ideal matrices α_{ij}^d and α_{ij}^u by Eqs. (9-11).

$$d_{ij}^+ = \frac{1}{2}(|\mu_{ij}^k - \mu_{ij}^+| + |\nu_{ij}^k - \nu_{ij}^+|), \quad (9)$$

$$d_{ij}^d = \frac{1}{2}(|\mu_{ij}^k - \mu_{ij}^d| + |\nu_{ij}^k - \nu_{ij}^d|), \quad (10)$$

$$d_{ij}^u = \frac{1}{2}(|\mu_{ij}^k - \mu_{ij}^u| + |\nu_{ij}^k - \nu_{ij}^u|) \quad (11)$$

Define the closeness coefficients of α_{ij}^k:

$$c_{ij}^k = \frac{d_{ij}^u + d_{ij}^d}{d_{ij}^u + d_{ij}^d + d_{ij}^+}. \quad (12)$$

The collective decision matrix $D = (\alpha_{ij})_{m\times n}$ consists of elements $\alpha_{ij} = w_{ij}^{(1)}\alpha_{ij}^{(1)} + \dots + w_{ij}^{(t)}\alpha_{ij}^{(t)}$, where an expert's weight C_k regarding the attribute B_j for the alternative A_i:

$$w_{ij}^{(k)} = \frac{c_{ij}^{(k)}}{\sum_{k=1}^t c_{ij}^{(k)}}, w_{ij}^{(k)} \geq 0, \sum_{k=1}^t \sum_{k=1}^t c_{ij}^{(k)}{}_{ij}^{(k)} = 1. \quad (13)$$

Step 4. If the attribute vector is completely unknown, find the attribute weight vector w_j based on the principle: the closer to fuzzy positive ideal value and farther from the intuitionistic fuzzy negative ideal, the large the weight is according to Eq. (14).

$$w_j = \frac{c_j}{\sum_{j=1}^n c_j} = \frac{\sum_{i=1}^m c_{ij}}{\sum_{j=1}^n \sum_{i=1}^m c_{ij}}, \quad (14)$$

where c_{ij} defines the closeness coefficient (Eq. 15) of experts' collective assessment α_{ij} regarding its distances to the positive ideal value $\alpha_j^+ = (1{,}0)$ and the negative ideal value $\alpha_j^- = (0{,}1)$,

$$c_{ij} = \frac{d(\alpha_{ij},\alpha_j^-)}{d(\alpha_{ij},\alpha_j^+)+d(\alpha_{ij},\alpha_j^-)}. \quad (15)$$

Step 5. Determine the weighted decision matrix $D' = (\alpha'_{ij})_{m\times n}$, where $\alpha'_{ij} = w_j\alpha_{ij}$, $W = (w_1, w_2, \dots, w_n)$ be the weight vector. If the latter is completely unknown, use the attribute vector found in Eqs. (14-15). If the attribute is given in advance, use the given value.

Step 6. Calculate the distance d^+ and d^- of each alternative's collective evaluation value to intuitionistic fuzzy positive ideal evaluation $A^+ = (\alpha_1^+, \alpha_2^+, \dots, \alpha_n^+)$ and intuitionistic fuzzy negative ideal evaluation value $A^- = (\alpha_1^-, \alpha_2^-, \dots, \alpha_n^-)$.

$$d_i^+ = \sum_{j=1}^n d(\alpha'_{ij}, \alpha_j^+), i = 1, \dots, m, \quad (16)$$

$$d_i^- = \sum_{j=1}^n d(\alpha'_{ij}, \alpha_j^-),\ i = 1, \dots, m. \quad (17)$$

Step 7. Calculate each alternative's closeness coefficient

$$c_i = \frac{d_i^-}{d_i^- + d_i^+}. \quad (18)$$

Step 8. Determine the rank of alternatives based on the alternatives' closeness coefficients [34].

B. Emergency Evacuation Based on the Maximum Dynamic Flow Finding

Present the Algorithm for emergency evacuation based on the maximum dynamic flow finding [39-41].

Step 1. Present the initial dynamic network as a static time-expanded network by making a node-time copy of each node-arc pair at each period $\theta \in T$ including the pair of nodes (x_i^-, x_i^+). The set of nodes X_e of the static time expanded network is $X_e = \{(x_i^+, x_i^-, \theta) \in X \times \mathrm{T}\}$. The set of arcs consists of arcs from the node-time pair $X_p = (x_i^+, x_i^-, \theta)$ to the node-time pair $\{(x_j^+, \vartheta = \theta + \tau_{(x_i^+, x_i^-) x_j^+}(\theta)$, where $x_j \in \Gamma(x_i)$ and $\theta + \tau_{(x_i^+, x_i^-) x_j^+}(\theta) \le p$. Arc capacities $\tilde{u}(x_i^+, x_i^-, \theta, \theta)$ that connect (x_i^+, θ) with (x_i^-, θ) are equal to w_i. Fuzzy arc capacities $\tilde{u}((x_i^+, x_i^-, \theta), (x_j^+, \vartheta))$ that connect (x_i^+, x_i^-, θ) with (x_j^+, ϑ) are equal to $\tilde{u}_{ij}(\theta)$. Traversal time parameters $\tau((x_i^+, x_i^-, \theta), (x_j^+, \vartheta))$ that connect (x_i^+, x_i^-, θ) c (x_j^+, ϑ) are equal to $\tau_{ij}(\theta)$, $w(x_i^+, x_i^-)$ equals w_j. Add dummy source S and sink T. Link them with true terminals by the arcs. Dummy arc capacities have infinite capacities.

Step 2. Transform the initial dynamic network $\tilde{G}$ into a time-spaced network $\tilde{G}^*$ by copying every node and arc at the specific time period along with converting the intermediate capacitated node x_i into the nodes x_i^+ and x_i^- with the arc capacity $\tilde{u}(x_i^+, x_i^-, \theta, \theta) = q(x_i)$.

Step 3. Pass the flow along the augmenting paths in the residual network $\tilde{G}^{*r}$.

3.1. If $\tilde{\xi}^{*r}(x_i^*, x_j^*, \theta, \vartheta) < \tilde{u}^*(x_i^*, x_j^*, \theta, \vartheta)$ in $\tilde{G}_e^{*r}$, then $\tilde{u}^{*r}(x_i^*, x_j^*, \theta, \vartheta) = \tilde{u}^*(x_i^*, x_j^*, \theta, \vartheta) - \tilde{\xi}^*(x_i^*, x_j^*, \theta, \vartheta)$.

If $\tilde{\xi}^*(x_i^*, x_j^*, \theta, \vartheta) > \tilde{0}$, then $\tilde{u}^{*r}(x_j^*, x_i^*, \vartheta, \theta) = \tilde{\xi}^*(x_i^*, x_j^*, \theta, \vartheta)$.

3.2. If a path exists, move to the step 4.

3.3 If there is no path to the sink, the maximum flow without intermediate storage to the destination t is found, turn to step 6.

Step 4. Pass the flow $\tilde{\sigma}^* = min\ [\tilde{u}^{*r}(x_i^*, x_j^*, \theta, \vartheta)]$, turn to the step 5.

Step 5. Find the augmenting paths from the intermediate nodes that allow storage to the sink T in priority order of nodes based on fuzzy intuitionistic TOPSIS method. The sink t has the highest priority; then there is the intermediate node x_i with the highest among others $q(x_i) > \tilde{0}$.

5.1 If a path exists, move back to the step 3

5.2 If there is no path, the maximum flow to the sink t is found, move to step 6

Step 6. Transform the evacuation flows:

6.1. For arcs joining $(x_j^{*\mu r}, \vartheta)$ and $(x_i^{*\mu r}, \theta)$, decrease the flow value $\tilde{\xi}^{\mu}(x_i^*, x_j^*, \theta, \vartheta)$ by the value $\tilde{\sigma}^{*\mu}$.

The total flow is $\tilde{\xi}^{\mu}(x_i^*, x_j^*\ \theta, \vartheta) - \tilde{\sigma}^{*\mu}$. Move back to the step 3.2.

6.2 For arcs joining $(x_i^{*\mu r}, \theta)$ and $(x_j^{*\mu r}, \vartheta)$, increase the flow value $\tilde{\xi}^{\mu}(x_i^*, x_j^*, \theta, \vartheta)$ by the value $\tilde{\sigma}^{*\mu}$.

Total flow value is $\tilde{\xi}^{\mu}(x_i^*, x_j^*, \theta, \vartheta) + \tilde{\sigma}^{*\mu}$ and turn to the step 3.2

Step 6. Remove dummy sinks and shelters. Turn to the original network.

IV. Case Study

In this section, we provide a case-study to simulate the emergency decision-making [3, 8, 42] in order to evacuate the maximum number of aggrieved from the dangerous area s and transport them to the safe shelter t. The evacuation is performed from the stadium Zenit in Saint Petersburg, Russia to the safe area. The safe pattern of evacuation considers storage at nodes so that to transport the maximum possible number of evacuees in two cases: with the defined attribute weight vector which is given in advance; and when the vector is completely unknown.

Fig. 1 shows the initial emergency network with the dangerous area s and the shelter t. Fig. 2 represents the real dynamic network in the form of a fuzzy graph within the time horizon T=4. Transit fuzzy arc capacities and traversal time parameters are given in Tables 1 and 2.

Figure 1. Real evacuation network

The peculiarity of the proposed method is the opportunity to apply intuitionistic fuzzy group decision-making to evacuation tasks, particularly, when experts should select the order of sink-nodes for safe evacuation. The approach based on group multi-criteria decision-making is the most effective way of tackling fuzzy input information, when there is a high level of doubts and experts' hesitation regarding membership and non-membership degrees of an element to a set.

The proposed method considers two cases of determining the attribute weight vector W. The first method relies on the assumption that attribute weights are unknown and will be defined throughout the algorithm. The second method is based on attribute weights given in advance. The proposed technique with unknown attribute weights refines the quality of the decision by reducing the impact of unreasonably high or low evaluation values.

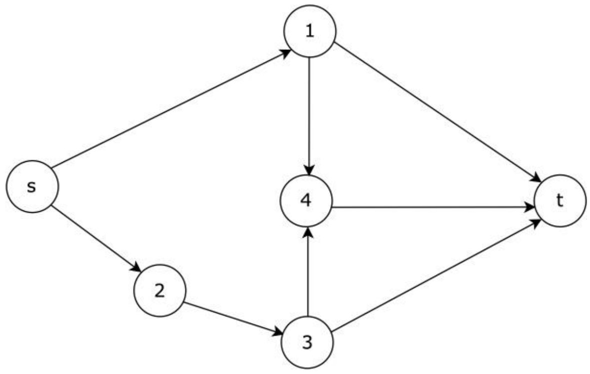

Figure 2. Graph image of the real network in Fig. 1

Table 1. Transit fuzzy arc capacities and traversal time parameters.

Transit arc capacities, $\tilde{u}_{ij}(\theta)$	Time parameters T				
	0	1	2	3	4
(s, x_1^+)	$\widetilde{90}$	$\widetilde{95}$	$\widetilde{80}$	$\widetilde{80}$	$\widetilde{75}$
(x_1^+, x_1^-)	$\widetilde{100}$	$\widetilde{100}$	$\widetilde{100}$	$\widetilde{100}$	$\widetilde{100}$
(x_1^-, x_3^+)	$\widetilde{97}$	$\widetilde{95}$	$\widetilde{102}$	$\widetilde{90}$	$\widetilde{90}$
(x_3^+, x_3^-)	$\widetilde{100}$	$\widetilde{100}$	$\widetilde{100}$	$\widetilde{100}$	$\widetilde{100}$
(x_3^-, x_4^+)	$\widetilde{72}$	$\widetilde{70}$	$\widetilde{70}$	$\widetilde{110}$	$\widetilde{110}$
(x_4^-, x_4^+)	$\widetilde{87}$	$\widetilde{87}$	$\widetilde{87}$	$\widetilde{87}$	$\widetilde{87}$
(s, x_2^+)	$\widetilde{130}$	$\widetilde{135}$	$\widetilde{100}$	$\widetilde{100}$	$\widetilde{90}$
(x_2^-, x_2^+)	$\widetilde{140}$	$\widetilde{140}$	$\widetilde{140}$	$\widetilde{140}$	$\widetilde{140}$
(x_2^-, x_4^+)	$\widetilde{72}$	$\widetilde{70}$	$\widetilde{56}$	$\widetilde{55}$	$\widetilde{60}$
(x_2^-, t)	$\widetilde{80}$	$\widetilde{80}$	$\widetilde{105}$	$\widetilde{55}$	$\widetilde{50}$
(x_3^-, t)	$\widetilde{70}$	$\widetilde{70}$	$\widetilde{70}$	$\widetilde{110}$	$\widetilde{100}$
(x_4^-, t)	$\widetilde{65}$	$\widetilde{65}$	$\widetilde{67}$	$\widetilde{68}$	$\widetilde{68}$

Table 2. Transit fuzzy arc capacities and traversal time parameters.

Transit arc capacities, $\tilde{u}_{ij}(\theta)$	Traversal time parameters $\tau_{ij}(\theta)$				
	0	1	2	3	4
(s, x_1^+)	1	1	1	2	1
(x_1^+, x_1^-)	0	0	0	0	0
(x_1^-, x_3^+)	1	1	1	1	1
(x_3^+, x_3^-)	0	0	0	0	0
(x_3^-, x_4^+)	1	1	1	1	2
(x_4^-, x_4^+)	0	0	0	0	0
(s, x_2^+)	1	1	1	1	1
(x_2^-, x_2^+)	0	0	0	0	0
(x_2^-, x_4^+)	1	1	1	1	2
(x_2^-, t)	0	1	1	1	1
(x_3^-, t)	1	1	1	1	1
(x_4^-, t)	1	1	1	1	1

Owing to the complexity of a decision-making task and incomplete information about the emergency, four decision makers C_i (i =1,...,4) are asked to assess the priority order of intermediate nodes x_1, x_2, x_3, x_4 for pushing additional number of aggrieved to the safe sink. Inherent uncertainty of decision-making problems makes experts to hesitate and be irresolute about the choice of membership function. Therefore, intuitionistic fuzzy assessments towards four attributes: the level of reachability (B_1), capacity of destination nodes (B_2), reliability (security) (B_3), and total expenses (B_4), are used to rank intermediate nodes.

To evacuate the maximum possible number of people from the dangerous area s to the safe destination t, we find the maximum *s-t* flow. Firstly, convert the dynamic network into the static (Fig. 3) by expanding the nodes and arcs of the network in time dimension.

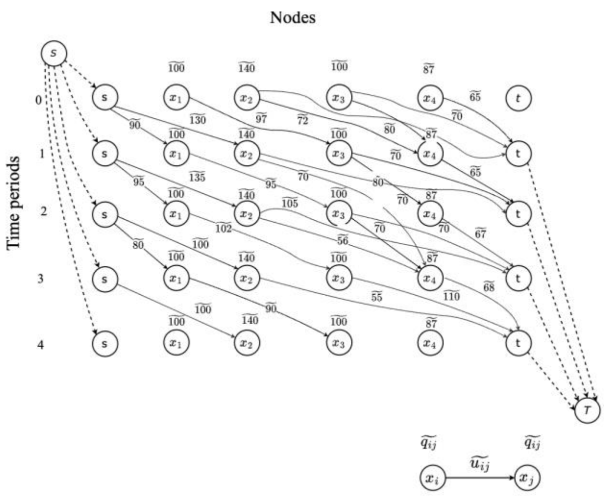

Figure 3. The static time-expanded network for graph in Fig. 2

Secondly, find the augmenting paths to transport the flows in the time-expanded network. Nodes and arcs of the following network have capacities. Then, convert the capacitated network in Fig. 3 into the network without node capacities (Fig. 4).

A series of paths with the corresponding flow distribution is found.

The sequences of augmenting paths are as follows:

1) $S \to s^0 \to x_2^{1+} \to x_2^{1-} \to t^2 \to T$ with $\widetilde{80}$ units.

2) $S \to s^0 \to x_2^{1+} \to x_2^{1-} \to x_4^{2+} \to x_4^{2-} \to t^3 \to T$ with $\widetilde{50}$ units.

3) $S \to s^0 \to x_1^{1+} \to x_1^{1-} \to x_3^{2+} \to x_3^{2-} \to t^3 \to T$ with $\widetilde{70}$ units.

4) $S \to s^0 \to x_1^{1+} \to x_1^{1-} \to x_3^{2+} \to x_3^{2-} \to x_4^{3+} \to x_4^{3-} \to t^4 \to T$ with $\widetilde{20}$ units.

5) $S \to s^1 \to x_2^{2+} \to x_2^{2-} \to t^3 \to T$ with $\widetilde{105}$ units.

6) $S \to s^1 \to x_2^{2+} \to x_2^{2-} \to x_4^{3+} \to x_4^{3-} \to t^4 \to T$ with $\widetilde{30}$ units.

6) $S \to s^1 \to x_1^{2+} \to x_1^{2-} \to x_3^{3+} \to x_3^{3-} \to t^4 \to T$ with $\widetilde{95}$ units.

7) $S \to s^2 \to x_2^{3+} \to x_2^{3-} \to t^4 \to T$ with $\widetilde{55}$ units.

Therefore, the total maximum *s-t* flow in the network without intermediate storage is $\widetilde{505}$ flow units, which is shown in Fig. 5.

To find extra flows with intermediate storage we should define the order of intermediate nodes for evacuating the aggrieved. Four experts provide the assessments of alternatives concerning attributes in Table 3 (Step 1 of the Algorithm).

Following the Step 2 of the intuitionistic TOPSIS algorithm, calculate intuitionistic fuzzy negative ideal decision matrices (Tables 4–5).

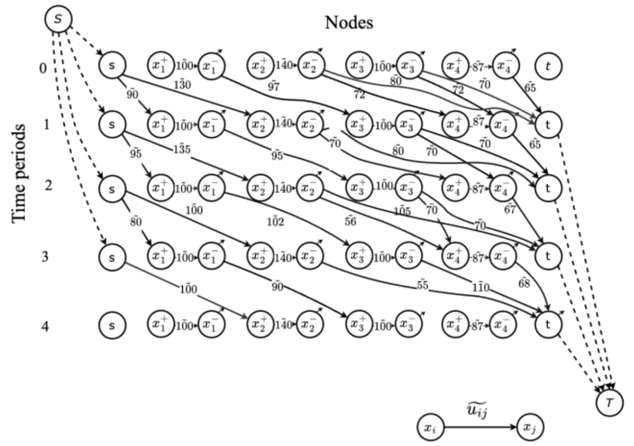

Figure 4. The network without node capacities

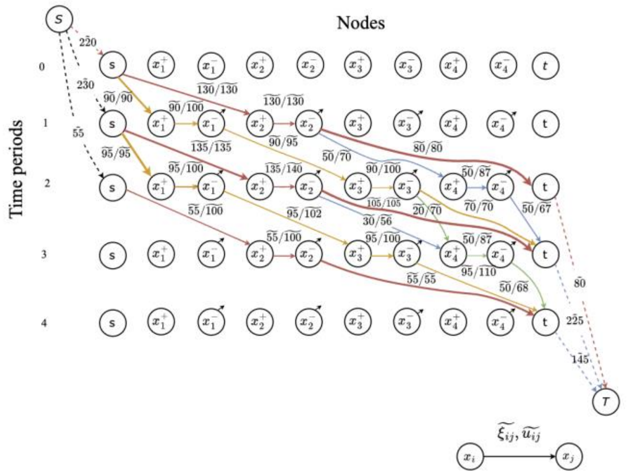

Figure 5. Network with maximum flow without intermediate storage

Table 3. Intuitionistic fuzzy decision matrix of the DMs.

	B_1	B_2	B_3	B_4
		C_1		
x_1	(0.5, 0.4)	(0.7, 0.3)	(0.4, 0.4)	(0.8, 0.1)
x_2	(0.7, 0.2)	(0.3, 0.5)	(0.6, 0.3)	(0.7, 0.1)
x_3	(0.4, 0.3)	(0.6, 0.3)	(0.8, 0.1)	(0.5, 0.2)
x_4	(0.3, 0.6)	(0.2, 0.7)	(0.7, 0.1)	(0.4, 0.5)
		C_2		
x_1	(0.6, 0.2)	(0.5, 0.4)	(0.5, 0.3)	(0.6, 0.3)
x_2	(0.5, 0.3)	(0.2, 0.6)	(0.4, 0.4)	(0.8, 0.1)
x_3	(0.5, 0.3)	(0.4, 0.3)	(0.6, 0.2)	(0.7, 0.1)
x_4	(0.2, 0.6)	(0.4, 0.5)	(0.5, 0.3)	(0.7, 0.2)
		C_3		
x_1	(0.3, 0.5)	(0.5, 0.2)	(0.6, 0.3)	(0.9, 0.1)
x_2	(0.5, 0.3)	(0.6, 0.2)	(0.5, 0.3)	(0.8, 0.1)
x_3	(0.4, 0.5)	(0.7, 0.1)	(0.6, 0.3)	(0.4, 0.5)
x_4	(0.2, 0.6)	(0.3, 0.5)	(0.4, 0.2)	(0.5, 0.4)
		C_4		
x_1	(0.2, 0.6)	(0.3, 0.6)	(0.7, 0.1)	(0.8, 0.1)
x_2	(0.5, 0.4)	(0.7, 0.2)	(0.4, 0.3)	(0.6, 0.1)
x_3	(0.3, 0.6)	(0.5, 0.3)	(0.3, 0.4)	(0.6, 0.2)
x_4	(0.4, 0.4)	(0.4, 0.5)	(0.2, 0.5)	(0.7, 0.1)

Table 4. Intuitionistic fuzzy negative ideal decision matrix D^u.

	B_1	B_2	B_3	B_4
x_1	(0.6,0.2)	(0.7,0.3)	(0.7,0.1)	(0.9,0.1)
x_2	(0.7,0.2)	(0.7,0.2)	(0.6,0.3)	(0.8,0.1)
x_3	(0.5,0.3)	(0.7,0.1)	(0.8,0.1)	(0.7,0.1)
x_4	(0.4,0.4)	(0.4,0.5)	(0.7,0.1)	(0.7,0.1)

Table 5. Intuitionistic fuzzy negative ideal decision matrix D^d.

	B_1	B_2	B_3	B_4
x_1	(0.2,0.6)	(0.3,0.6)	(0.4,0.4)	(0.6,0.3)
x_2	(0.5,0.4)	(0.2,0.6)	(0.4,0.4)	(0.6,0.1)
x_3	(0.3,0.6)	(0.4,0.3)	(0.3,0.4)	(0.4,0.5)
x_4	(0.2,0.6)	(0.2,0.7)	(0.2,0.5)	(0.4,0.5)

Fuzzy positive ideal decision matrix is shown in Table 6.

Table 6. Intuitionistic fuzzy positive ideal decision matrix D^+.

	B_1	B_2	B_3	B_4
x_1	(0.421, 0.394)	(0.521, 0.322)	(0.564, 0.245)	(0.799, 0.131)
x_2	(0.560, 0.291)	(0.491, 0.331)	(0.482, 0.322)	(0.737, 0.100)
x_3	(0.404, 0.405)	(0.564, 0.228)	(0.613, 0.221)	(0.564, 0.211)
x_4	(0.280, 0.542)	(0.330, 0.544)	(0.482, 0.234)	(0.595, 0.251)

Intuitionistic fuzzy collective decision matrix is calculated according to Eq. (13) and presented in Table 7.

Table 7. Intuitionistic fuzzy collective decision matrix D.

	B_1	B_2	B_3	B_4
x_1	(0.426, 0.395)	(0.531, 0.305)	(0.565, 0.249)	(0.809, 0.121)
x_2	(0.550, 0.295)	(0.503, 0.319)	(0.482, 0.320)	(0.742, 0.100)
x_3	(0.407, 0.400)	(0.563, 0.235)	(0.619, 0.219)	(0.569, 0.203)
x_4	(0.274, 0.552)	(0.337, 0.534)	(0.486, 0.230)	(0.604, 0.243)

Case 1. If the attribute weight vector is completely unknown, find it according to the Eqs. (14-15).

Attribute weight vector: $w_j = (0.207, 0.233, 0.248, 0.312)$.

Intuitionistic fuzzy collective weighted decision matrix is presented in Table 8.

Table 8. Intuitionistic fuzzy weighted decision matrix D'

	B_1	B_2	B_3	B_4
x_1	(0.108, 0.825)	(0.161, 0.759)	(0.187, 0.708)	(0.404, 0.518)

x_2	(0.152, 0.777)	(0.150, 0.767)	(0.151, 0.753)	(0.345, 0.487)
x_3	(0.102, 0.827)	(0.175, 0.714)	(0.213, 0.686)	(0.231, 0.608)
x_4	(0.064, 0.884)	(0.091, 0.864)	(0.152, 0.694)	(0.251, 0.643)

Calculate the distances of alternatives' evaluation values to the values A^{+} and A^{-} by Eqs. (16-17):

$$d_1^+ = 2.975,\ d_2^+ = 2.993,\ d_3^+ = 3.057,\ d_4^+ = 3.263,$$
$$d_1^- = 1.025,\ d_2^- = 1.007,\ d_3^- = 0.943,\ d_4^- = 0.737.$$

The relative closeness coefficients are found using Eq. (18):

$$c_1 = 0.256,\ c_2 = 0.252,\ c_3 = 0.236,\ c_4 = 0.184.$$

The alternatives thus are ranked as: $x_1 \succ x_2 \succ x_3 \succ x_4$.

In order to find extra flow with intermediate storage, push the additional flow which is stored at nodes to evacuate the maximum number of aggrieved to the nodes in the found order $x_1 \succ x_2 \succ x_3 \succ x_4$.

Finally, we have the augmenting paths with additional flows:

1) $S \to s^2 \to x_1^{3+} \to x_1^{3-} \to T$ with $\widetilde{80}$ units.
2) $S \to s^2 \to x_2^{3+} \to x_2^{3-} \to T$ with $\widetilde{45}$ units.
3) $S \to s^3 \to x_2^{4+} \to x_2^{4-} \to T$ with $\widetilde{100}$ units.

The corresponding paths which satisfy the condition of intermediate storage at nodes are presented in Fig. 6.

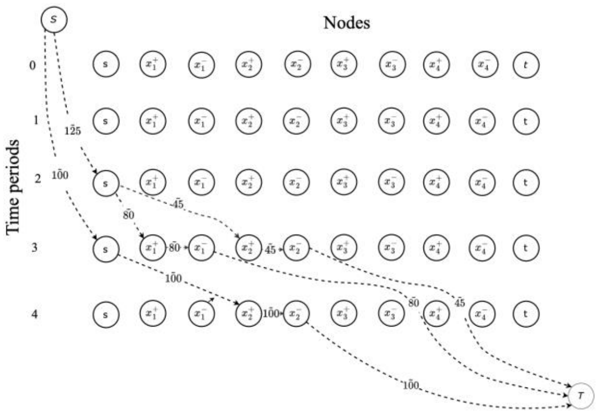

Figure 6. Additional paths for intermediate storage

The total maximum flow considering intermediate storage at nodes is $\widetilde{730}$ flow units, which is presented in Fig. 7.

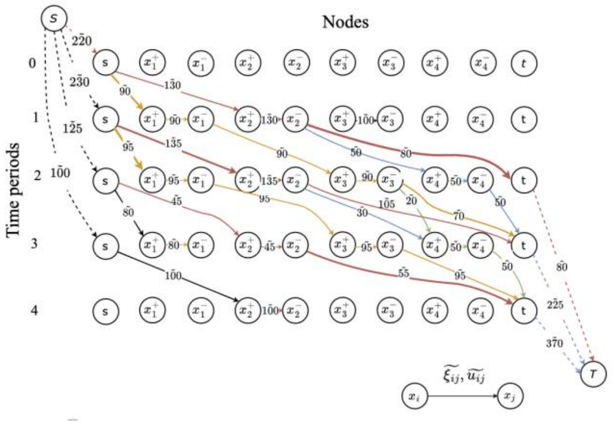

Figure 7. Final network with maximum flow with intermediate storage

Case 2. The vector of attribute weight is given beforehand.

Assume that the vector of attribute weights is equal to [0.1, 0.1, 0.6, 0.2].

Intuitionistic fuzzy negative ideal decision matrix D^u, intuitionistic fuzzy negative ideal decision matrix D^d, intuitionistic fuzzy positive ideal decision matrix D^+, and intuitionistic fuzzy collective decision matrix D remain the same and are given in Tables 3-6.

Find intuitionistic fuzzy weighted decision matrix D' by Eq. (14). The result is shown in Table 9.

Table 9. Intuitionistic fuzzy weighted decision matrix D'

	B_1	B_2	B_3	B_4
x_1	(0.054, 0.911)	(0.073, 0.888)	(0.393, 0.435)	(0.282, 0.656)
x_2	(0.077, 0.885)	(0.068, 0.892)	(0.326, 0.504)	(0.237, 0.631)
x_3	(0.051, 0.912)	(0.079, 0.865)	(0.439, 0.402)	(0.155, 0.727)
x_4	(0.032, 0.942)	(0.040, 0.939)	(0.329, 0.414)	(0.169, 0.754)

Calculate the distances of alternatives' evaluation values to the values A^{+} and A^{-} by Eqs. (16-17):

$$d_1^+ = 3.044,\ d_2^+ = 3.102,\ d_3^+ = 3.091,\ d_4^+ = 3.240,$$
$$d_1^- = 0.956,\ d_2^- = 0.898,\ d_3^- = 0.909,\ d_4^- = 0.760.$$

The relative closeness coefficients are found using Eq. (18):

$$c_1 = 0.239,\ c_2 = 0.224,\ c_3 = 0.227,\ c_4 = 0.190.$$

The alternatives thus are ranked as: $x_1 \succ x_3 \succ x_2 \succ x_4$.

The results of the Case 2 differ from the alternatives obtained throughout the Case 1. It means that the algorithm is sensible to the value of attribute weight vector.

In order to find extra flow with intermediate storage, push the additional flow which is stored at nodes to evacuate the maximum number of aggrieved to the nodes in the found order $x_1 \succ x_3 \succ x_2 \succ x_4$.

We have the following augmenting paths with additional flow:

1) $S \to s^2 \to x_1^{3+} \to x_1^{3-} \to T$ with $\widetilde{80}$ units.
2) $S \to s^2 \to x_2^{3+} \to x_2^{3-} \to T$ with $\widetilde{45}$ units.
3) $S \to s^3 \to x_2^{4+} \to x_2^{4-} \to T$ with $\widetilde{100}$ units.

The maximum flow with intermediate storage remains the same and it is equal to $\widetilde{730}$ flow units.

V. The Method Based on the Linear Combinations of Spreads to Handle Triangular Fuzzy Numbers

Let us consider the method which allows tackling fuzzy parameters of the evacuation network. Conventual calculations with fuzzy numbers lead to the strong extension of the final fuzzy number [43] and obtaining unreliable solution. To overcome this drawback, linear combinations of spreads are used throughout the algorithm. Suppose that fuzzy evaluations of arc capacities are presented on the number axis. In order to calculate the values of deviations, the total fuzzy number is defined by values of adjacent numbers. Let the fuzzy parameter "near a'" be between two adjacent values "near a_1" and "near a_2" ($a_1 \le a' \le a_2$). Triangular membership functions of these numbers are $\mu_{a_1}(a_1)$ and

$\mu_{a_2}(a_2)$. Spreads of the membership function $\mu_{a'}(a)$ regarding the fuzzy parameter "near $\tilde{x}'$" are defined by a linear combination of the left and right spreads of adjacent values (Eq. 19):

$$l^L = \frac{(a_2 - a')}{(a_2 - a_1)} \times l_1^L + \left(1 - \frac{(a_2 - a')}{(a_2 - a_1)}\right) \times l_2^L$$
$$l^R = \frac{(a_2 - a')}{(a_2 - a_1)} \times l_1^R + \left(1 - \frac{(a_2 - a')}{(a_2 - a_1)}\right) \times l_2^R, \quad (19)$$

where $l^L$is the left spread of the fuzzy triangular number with the center a_1; l^R – the right spread of the fuzzy triangular number with the center a_2.

Fig. 8 shows the approach for defining a membership function of a fuzzy number by membership functions of adjacent triangular numbers. When the center of a required triangular number coincides with the value on the number axis, the spreads of this number are equal to the spreads of the existing number. If the center of a required parameter precedes the center of the first value on the number axis, its spreads coincide with those which are located on the axis. In addition, it is also valid for the case when the required center follows the center of the last number marked on the axis.

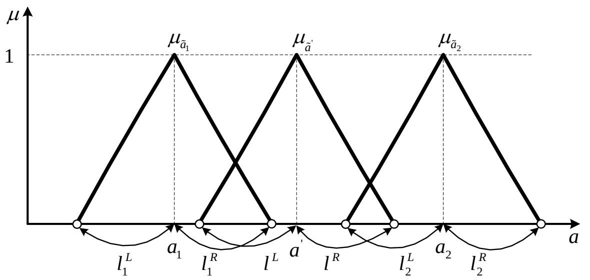

Figure 8. Defining the membership function $\mu_{a'}(a)$

Therefore, throughout the algorithm the centers of triangular numbers will be used; the spreads will be calculated at the end of the algorithm to find the final triangular number.

The maximum flow with intermediate storage is $\widetilde{730}$ flow units. Apply the method based on linear combinations of spreads to find the spreads of the desired fuzzy triangular number with the center $\widetilde{730}$ unit. Expert' assessments are given in Fig. 9, which shows the spreads of basic numbers.

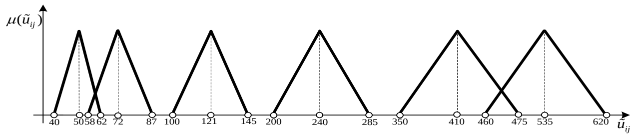

Figure 9. Membership functions of the basic values of arc capacities of the evacuation network

Calculate the deviations based on Eq. (19). The desired flow value follows the last basic value of the arc capacities: $\widetilde{535}$ units with the left spread $l_1^L = 75$, the right spread – $l_1^R = 85$. Therefore, the spreads of desired fuzzy number coincide with deviations of the last basic number. Finally, the maximum evacuation flow with intermediate storage is (655, 730, 815) units.

VI. Conclusion and Future Scope

The paper illustrates the approach for evacuation the maximum amount of aggrieved from the dangerous area to the safe destination so that the intermediate nodes can store the evacuees. This method enables maximizing the total amount of flow by pushing the maximum amount of flow from the source. The order of nodes for transporting aggrieved to the sink is found by MAGDM algorithm in intuitionistic environment based on TOPSIS. Group decision-making is required since one expert cannot have enough professional knowledge of each aspect of evacuation to make reasonable decisions. Two cases regarding the attribute weights are considered: 1) attribute weights are given beforehand; 2) attribute weights are completely unknown. In the second case, the weights are defined according to the principle that the attribute whose evaluation value is close to the positive ideal evaluation and far from negative ideal evaluation values has a large weight. The proposed method handles intuitionistic fuzzy values of experts' assessments because of inherent hesitation in exact membership degrees. This technique enables experts to consider the degree of membership, non-membership and hesitation. A case study which consists of two cases is conducted to simulate the evacuation of the maximum number of evacuees with storage at intermediate nodes when attribute weights are known beforehand and when they are completely unknown. MAGDM algorithm in intuitionistic environment based on TOPSIS is used to rank the shelters for evacuation. Abstract flow models in fuzzy environment will be proposed to evacuate the maximum amount of people as a part of the future research.

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