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ORIGINAL PAPER

# Evacuation strategy of emergent event in metro station based on the ELECTRE method

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**Abstract**
Metro station is crowded during rush hours and the structure is usually complex. Hence, the determination of an optimal evacuation strategy is the key for improving the evacuation process efficiency when an emergency event happens. A group decision-making model based on triangular intuitionistic fuzzy numbers (TIFNs) theory is developed for selecting an evacuation strategy in metro station. In this model, a group of experts elicit their preferences about the different evacuation strategies using TIFNs for multiple criteria. The Elimination Et Choice Translation Reality (ELECTRE) method is used to sort the different emergency evacuation strategies proposed for the metro station, and it should be adapted to manage TIFNs above all. The TIFN-ELECTRE model is proposed and applied to select the best emergency evacuation strategy of metro station. Finally, a numerical example with respect to the emergency evacuation strategy of Wuhan Guanggu Square station is carried out.

**Keywords** ELECTRE · Metro station · Emergent event · Emergency evacuation · Evacuation strategies

## 1 Introduction

Metro is a sort of fast, convenient, and energy-saving transportation, which has advantages in environmental protection and relieving urban traffic congestion. In recent years, a new upsurge of building the metro in domestic and foreign central cities is in the building to create a convenient urban transportation network and offer people convenience. However, the metro station space is long and narrow, which has high population density and complex structure. Once the emergencies occur such as fire and earthquake, it is easy to cause mass die-offs and injury which initiated crowd stampedes. At the same time, the metro station as a crowded public place is easy to breed some illegal and criminal behavior, such as 2010 and 2011 in Belarus; metro explosion terrorist attack took place in Belgium in 2016; Vicious hacking caused in Taipei and Guangzhou metro station in 2014, Hong Kong metro station in 2015, and New York metro in 2016. The event of self-ignition occurred in Hong Kong metro station. With metro trip more and more popular, the security problem of metro station has gradually been paid attention. In the event of an emergency, it is critical to choose the correct evacuation strategy and evacuate quickly.

The reminder of the paper is organized as follows. In Sect. 2, the literature about the evacuation strategy and evacuation model is reviewed. Section 3 constructs a concept model of evacuation strategy in metro station based on the Elimination Et Choice Translation Reality (ELECTRE) approach. In Sect. 4, an evacuation strategy selection model and the specific calculation steps are formulated. Section 5 discusses and applies the proposed methods to the evacuation strategy selection of metro station in emergency context. Finally, some further discussions on the proposed methodology and conclusions are given in Sect. 6.

## 2 Literature review

Appropriate evacuation strategies have great contribution to quickly evacuate people into safe places, which is a good way to reduce the loss of people or property when the emergencies occur in crowded public places. From the perspective of evacuation time, Lovell and Daganzo (2000) proposed a real-time evacuation strategy, which required the minimum evacuation time of the evacuation network.

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The phased evacuation strategy which divides the evacuation area into $N$ sub-regions controls the evacuation process through the time of reaching each region (Adelizadeh et al. 2017). In view of the heterogeneity of evacuated populations, some preferential evacuation strategies were presented where the vulnerable groups preferred to be evacuated (Noh et al. 2016). According to the different areas of the emergency, Wang et al. (2014) put forward a regional priority evacuation strategy, which ranked the regional risk category and the crowd was evacuated in high risk of region. Besides, the guiding strategies of authoritative figures that treated as an agent were explored (Song et al. 2017), and the strategy is implemented to conduct the crowd to low-density region or nearest exit in the context of known location of the exit and the population density.

In addition, Nguyen et al. (2013) studied the evacuation model of smoke effect and blind evacuation strategy (SEBES) based on agent and optimized the evacuation strategy. From the visualization level in the event of fire emergencies, the diffusion and influence of smoke was taken into account. The improved field cellular automata model was employed to analyze the initial distribution of non-uniform pedestrian evacuation problems, which improved the evacuation efficiency by maintaining a pedestrian's maximum radius of viewing (Pereira et al. 2017). Hu et al. (2014) adopted the actual evacuation system and artificial evacuation system parallel implementation of the idea and applied artificial system, computing experiments, parallel execution (ACP) method to address the problem of emergency evacuation strategy in management level under fire environment. The parallel emergency management dynamics model was established based on a KD-ACP platform (Meng et al. 2015). Furthermore, Wu et al. (2013) constructed the Agent path selection model using $A^*$ algorithm and discussed the three path selection strategies based on the shortest distance, the shortest time, and the mixed type. The results indicated that overall evacuation time of various evacuation strategies has no difference under the walking mode.

In view of the selection and optimization of evacuation strategy, So and Daganzo (2010) provided two necessary conditions to choose the evacuation strategy: (1) the maximum flow of evacuation path; (2) the shortest evacuation time. Liu et al. (2016) applied ant colony algorithm to study the evacuation path selection and optimization. Abdelghany et al. (2014) evaluated the evacuation strategy by simulation model and adopted genetic algorithm to filter the optimal strategy. In addition, a multi-stage time-varying quickest flow (MSTVQF) method was proposed for building evacuation planning design and evaluation (Lin et al. 2008). Chen et al. (2014) applied the real-time hotspot graph, Baidu map data, and computer simulation software BUILDING EXODUS to simulate the evacuation of high-rise building, which improved the evacuation efficiency of large-scale emergency response system through ordered index and location service. A path planning method was shown based on multi-criteria decision-making for the evacuation of metro stations and selected four key performance indicators (KPI) to evaluate the evacuation efficiency of different evacuation strategies and implement system simulation (Zhang et al. 2016). Moreover, many decision-making theory and approaches can introduce metro station safety decision, such as granular computing, which is a new way to describe problem (Pedrycz and Chen 2011, 2015a, b).

All the analysis shows the existing research on evacuation strategy mainly involves the following three aspects: (1) types of evacuation strategy; (2) optimization on evacuation strategy; (3) evaluation and selection of evacuation strategy. It should be pointed out that existing evaluation and selection of evacuation strategies neglect the time constraints and the limitations of decision-making experience of decision makers. This paper employs the intuitionistc fuzzy number to describe the decision information, which can represent the uncertainty information by hesitancy degree. It is a good way to improve the rationality and validity of metro station emergency evacuation strategy selection model.

## 3 Concept model of evacuation strategy in metro station based on the ELECTRE method

With large-scale construction and operation of metro, it is important to improve the level of metro station safety management. In the process of unexpected events in metro station, selecting the most appropriate evacuation strategy and adopting positive and rapid response become vital during emergency evacuation of metro stations. On account of the limitation of the space and the density of the population, it is necessary for the decision makers to make quick and effective decisions on the evacuation strategy in allusion to diversified emergencies to ensure the safety of the personnel and reduce property damage. However, it is often difficult for decision makers to make precise decisions in a limited time. This paper presents the conceptual model of the evacuation strategy of the metro station based on triangular intuitionistic fuzzy number (TIFN) (Fig. 1).

As shown in Fig. 1, with the development of metro station, the metro station is equipped with a more complete monitoring system for different emergencies, which includes fire for fire alarm, temperature control alarm, smoke alarm equipment, and video surveillance system. They are employed to cope with natural disasters such as unexpected weather events as well as earthquake detection systems. After receiving the alarm of the different monitoring system, the staff carries out on-site confirmation and assessment of the incident to determine whether dispersing the crowd in

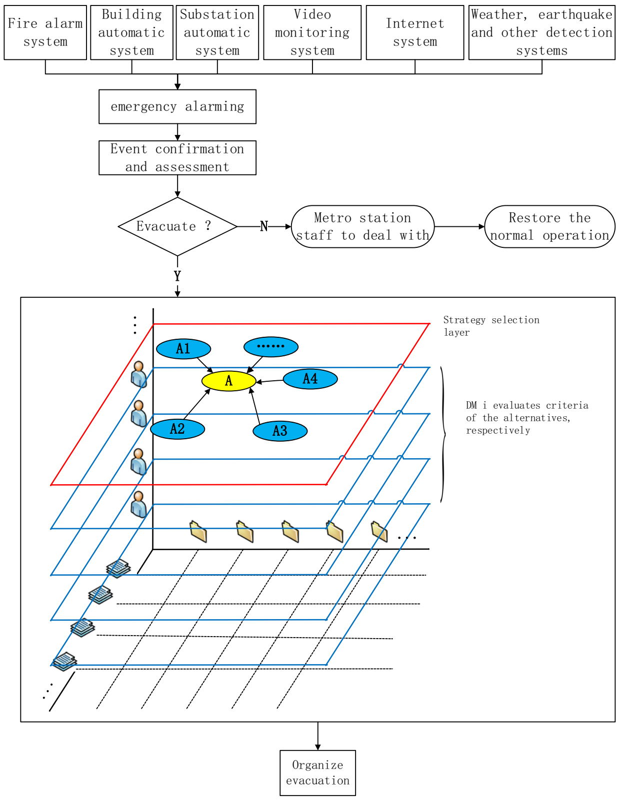


**Fig. 1** Conceptual model of evacuation strategy selection for metro station

the metro station. If the scope of the influence is small, it does not need evacuate the crowd. After the emergency treatment, the metro station will resume normal operation. If the incident is terrible and has a threat for passenger and property safety in big scope, correct crowd evacuation strategy is required for organizing the rapid evacuation. Therefore, reasonable evacuation strategy on the crowd is significant importance.

In the metro station emergency evacuation strategy selection system, assume the decision makers $P = \{P_1, P_2, \ldots, P_k\}$, the set of alternatives $S = \{S_1, S_2, \ldots, S_m\}$, and the criteria set $C = \{C_1, C_2, \ldots, C_n\}$. Each decision maker evaluates different evacuation strategies according to multiple criteria by using linguistic variables, which is transformed to into triangular intuitionistic fuzzy numbers and obtains the corresponding strategy evaluation matrix (as shown in Fig. 1 in the blue border layer). It can solve the problem that the object cannot be accurately measured only using natural language evaluation. The idea in this paper is expressed as follows: first, the strategy evaluation set of each decision maker is integrated and projected to the corresponding strategy selection layer (as shown in the red border layer in the Fig. 1). Furthermore, the information set projected to selection layer is integrated again. Finally, the classical the ELECTRE method is adopted to rank all strategies and select the appropriate evacuation strategy consistent with the current situation, so that the rapid evacuation is organized.

## 4 Selection model and algorithm of emergency evacuation strategy in metro station based on the ELECTRE method

Based on the above theoretical basis, this paper proposes the following strategy selection model and the corresponding algorithm for the emergency evacuation strategy selection of unexpected event in the metro station.

### 4.1 4.1 Preliminaries

**Definition 1** (Xu 2010) Let $\tilde{a} = \left\langle \left(\underline{a}, a, \bar{a}\right); \mu_{\tilde{a}}, \nu_{\tilde{a}} \right\rangle$ be a triangular intuitionistic fuzzy sets; membership function and non-membership function are defined as follows:

$$\mu_{\tilde{a}} = \begin{cases} \frac{(x-\underline{a})q_{\tilde{a}}}{a-\underline{a}}, & \underline{a} < x < a \\ q_{\tilde{a}}, & x = a \\ \frac{(\bar{a}-x)q_{\tilde{a}}}{\bar{a}-a}, & a < x < \bar{a} \\ 0, & x < \underline{a} \;\; or \;\; x > \bar{a} \end{cases} \tag{1}$$

$$\nu_{\tilde{a}} = \begin{cases} \frac{\left[a-x+p_{\tilde{a}}(x-\underline{a})\right]}{(a-\underline{a})}, & \underline{a} < x < a \\ p_{\tilde{a}}, & x = a \\ \frac{\left[x-a+p_{\tilde{a}}(\bar{a}-x)\right]}{(\bar{a}-a)}, & a < x < \bar{a} \\ 1, & x < \underline{a} \text{ or } x > \bar{a} \end{cases}, \tag{2}$$

where $u_{\tilde{a}} \in [0,1], \nu_{\tilde{a}} \in [0,1]$ and $0 \le \mu_{\tilde{a}} + \nu_{\tilde{a}} \le 1$. $q_{\tilde{a}} = \max\{u_{\tilde{a}}\}$ and $p_{\tilde{a}} = \min\{\nu_{\tilde{a}}\}$. $0 < q_{\tilde{a}} < 1$, $0 < p_{\tilde{a}} < 1$ represent the maximum membership degree and the minimum non-membership degree, respectively. In addition, $\pi_{\tilde{a}} = 1 - u_{\tilde{a}} - \nu_{\tilde{a}}$, $\pi_{\tilde{a}}$ is called the hesitation degree of triangular intuitionistic fuzzy numbers. When $u_{\tilde{a}} + \nu_{\tilde{a}} = 1$ is satisfied, triangular intuitionistic fuzzy numbers are reduced to fuzzy numbers.

According to the literature (Li 2010; Wang et al. 2015, Wang and Hsuan 2007), the basic operations axioms concerning TIFN are defined as follows.

**Definition 2** (Li 2010; Wang et al. 2015, Wang and Hsuan 2007) Let $\tilde{a} = \left\langle \left(\underline{a}, a, \bar{a}\right); u_{\tilde{a}}, \nu_{\tilde{a}} \right\rangle$ and $\tilde{b} = \left\langle \left(\underline{b}, b, \bar{b}\right); u_{\tilde{b}}, \nu_{\tilde{b}} \right\rangle$ be two TIFNs and $\lambda$ a real number. The basic operations axioms are defined as follows:

Addition operation:

$$\tilde{a}+\tilde{b}=\left\langle\left(\underline{a}+\underline{b},a+b,\bar{a}+\bar{b}\right);\frac{Au_{\tilde{a}}+Bu_{\tilde{b}}}{A+B},\frac{Av_{\tilde{a}}+Bv_{\tilde{b}}}{A+B}\right\rangle. \tag{3}$$

Subtraction operation:

$$\tilde{a}-\tilde{b}=\left\langle\left(\underline{a}-\underline{b},a-b,\bar{a}-\bar{b}\right);\frac{Au_{\tilde{a}}+Bu_{\tilde{b}}}{A+B},\frac{Av_{\tilde{a}}+Bv_{\tilde{b}}}{A+B}\right\rangle. \tag{4}$$

Multiplication operation:

$$\tilde{a}\tilde{b}=\begin{cases}\left\langle\left(\underline{ab},ab,\bar{a}\bar{b}\right);\mu_{\tilde{a}}\mu_{\tilde{b}},v_{\tilde{a}}+v_{\tilde{b}}-v_{\tilde{a}}v_{\tilde{b}}\right\rangle,\tilde{a}>0,\tilde{b}>0\\ \left\langle\left(\underline{a}\bar{b},ab,\bar{a}\underline{b}\right);\mu_{\tilde{a}}\mu_{\tilde{b}},v_{\tilde{a}}+v_{\tilde{b}}-v_{\tilde{a}}v_{\tilde{b}}\right\rangle,\tilde{a}<0,\tilde{b}>0.\\ \left\langle\left(\bar{a}\bar{b},ab,\underline{ab}\right);\mu_{\tilde{a}}\mu_{\tilde{b}},v_{\tilde{a}}+v_{\tilde{b}}-v_{\tilde{a}}v_{\tilde{b}}\right\rangle,\tilde{a}<0,\tilde{b}<0\end{cases} \tag{5}$$

Division operation:

$$\tilde{a}/\tilde{b}=\begin{cases}\left\langle\left(\underline{a}/\bar{b},a/b,\bar{a}/\underline{b}\right);\mu_{\tilde{a}}\mu_{\tilde{b}},v_{\tilde{a}}+v_{\tilde{b}}-v_{\tilde{a}}v_{\tilde{b}}\right\rangle,\tilde{a}>0,\tilde{b}>0\\ \left\langle\left(\bar{a}/\bar{b},a/b,\underline{a}/\underline{b}\right);\mu_{\tilde{a}}\mu_{\tilde{b}},v_{\tilde{a}}+v_{\tilde{b}}-v_{\tilde{a}}v_{\tilde{b}}\right\rangle,\tilde{a}<0,\tilde{b}>0.\\ \left\langle\left(\bar{a}/\underline{b},a/b,\underline{a}/\bar{b}\right);\mu_{\tilde{a}}\mu_{\tilde{b}},v_{\tilde{a}}+v_{\tilde{b}}-v_{\tilde{a}}v_{\tilde{b}}\right\rangle,\tilde{a}<0,\tilde{b}<0\end{cases} \tag{6}$$

Scalar multiplication operation:

$$\lambda\tilde{a}=\begin{cases}\left\langle\left(\lambda\underline{a},\lambda a,\lambda\bar{a}\right);\mu_{\tilde{a}},v_{\tilde{a}}\right\rangle, & \text{if } \lambda>0\\ \left\langle\left(\lambda\bar{a},\lambda a,\lambda\underline{a}\right);\mu_{\tilde{a}},v_{\tilde{a}}\right\rangle, & \text{if } \lambda<0\end{cases}. \tag{7}$$

where $A=\frac{|\underline{a}|+2a+|\bar{a}|}{4}$, $B=\frac{|\underline{b}|+2b+|\bar{b}|}{4}$..

According to Li (2010), and Devi and Yadav (2013), the triangular fuzzy number transformed into the classical numerical method is given as follows:

**Definition 3** (Li 2010; Devi and Yadav 2013) Let $F=\{M_1,M_2,\ldots,M_n\}$ be a set of TIFNs and a TIFN $M_j=\left\langle\left(\underline{m}_j,m_j,\bar{m}_j\right);\mu_{M_j},v_{M_j}\right\rangle$ be calculated by $L(F)$, $U(F)$, and $S(M_j)$. $T_F(M_j)$ is expressed as follows:

$$T_F(M_j)=\frac{\int_0^1\left(\left(M_j\right)_\alpha^L-L(F)\right)d_\alpha}{\int_0^1\left(\left(M_j\right)_\alpha^L-L(F)\right)d_\alpha+\int_0^1\left(U(F)-\left(M_j\right)_\alpha^U\right)d_\alpha}S(M_j), \tag{8}$$

where $L(F)=\min_{1\le j\le n}\underline{m}_j$, $U(F)=\max_{1\le j\le n}\bar{m}_j$, $S(M_j)=u_{M_j}+\frac{u_{M_j}}{u_{M_j}+v_{M_j}}\pi_{M_j}$.

**Lemma 3.1** (Li 2010; Devi and Yadav 2013) *$M_j=\left\langle\left(\underline{m}_j,m_j,\bar{m}_j\right);u_{M_j},v_{M_j}\right\rangle$ is a TIFN in a set of TIFN F, then*

$$T_F(M_j)=\frac{\underline{m}_j+m_j-2L(F)}{\underline{m}_j-\bar{m}_j+2(U(F)-L(F))}S(M_j), \tag{9}$$

where $L(F)=\min_{1\le j\le n}\underline{m}_j$, $U(F)=\max_{1\le j\le n}\bar{m}_j$, $S(M_j)=u_{M_j}+\frac{u_{M_j}}{u_{M_j}+v_{M_j}}\pi_{M_j}$.

## 4.2 Selection model and algorithm of emergency evacuation strategy in metro station

### Hypothesis

1. A set of evacuation strategy accordingly has developed according to the specific metro station emergencies.
2. Assuming that the incident has occurred and large-scale evacuation must be carried out. It means that the contingency plan should be initiated.
3. The evacuees fully abide by arrangement in the metro station.
4. Emergency evacuation strategy selection model in metro station

According to the characteristics of the metro station and the particularity of the expert data, the selection model is put forward based on the TIFN-ELECTRE evacuation strategy. Evaluation level is usually divided into five or seven scales (Dong et al. 2016). Five scales are employed in this paper. Index weights include very low (VL), low (L), medium (M), high (H), and very high (VH); the evaluation value of the index can be divided into very poor (VP), poor (P), fair (F), medium good (MG), good (G), and very good (VG), as shown in Table 1. The fuzzy semantic variables are transformed into triangular fuzzy numbers according to the literature (Atanassov 1986; Yeh 2017). The decision makers describe the criteria weights and the criteria evaluation values adopt TIFN.

*Step 1* The decision makers select and evaluate the appropriate evacuation strategy according to the specific emergencies. Furthermore, the weight judgment matrix and the

**Table 1** Fuzzy evaluation and weight class semantics

| Semantics variables | VL<br>VP | L<br>P | M<br>F | H<br>G | VH<br>VG |
|---|---|---|---|---|---|
| TIFN | (0, 0, 0.3) | (0,0.25,0.5) | (0.3,0.5,0.7) | (0.5,0.75,1) | (0.7,1,1) |

evacuation strategy judgment matrix are obtained, where the expert weights is $W_P = \left(W_{P_1}, W_{P_2}, \dots, W_{P_k}\right)$.

$$P_i = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ S_1 & a_{11} & a_{12} & \cdots & a_{1n} \\ S_2 & a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ S_m & a_{m1} & a_{m2} & \cdots & a_{mn} \end{matrix} \quad i = 1, 2, \dots, k. \tag{10}$$

$$W_c = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ P_1 & w_{11} & w_{12} & \cdots & w_{1n} \\ P_2 & w_{21} & w_{22} & \cdots & w_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ P_m & w_{k1} & w_{k2} & \cdots & w_{kn} \end{matrix} \quad i = 1, 2, \dots, k. \tag{11}$$

Equation (10) indicates that the decision maker evaluates the evacuation strategy set $S$ and obtains the evacuation strategy judgment matrix. Equation (11) indicates that the decision maker evaluates index weights to obtain the weight judgment matrix.

*Step 2* Calculate the fuzzy mean value and derive the group decision matrix. Different decision makers have different degrees of recognition for different indicators. Accordingly, weighted average method is adopted to integrate the information of index and weights:

$$a'_{ij} = \sum_{i=1}^{k} W_{P_i}\tilde{a}_{ij} = \left\langle \left( \sum_{i=1}^{k} W_{P_i}\underline{a}, \sum_{i=1}^{k} W_{P_i}a, \sum_{i=1}^{k} W_{P_i}\bar{a} \right); \frac{\sum_{i=1}^{k} A_i \mu_{a_{ij}}}{\sum_{i=1}^{k} A_i}, \frac{\sum_{i=1}^{k} A_i v_{a_{ij}}}{\sum_{i=1}^{k} A_i} \right\rangle \tag{12}$$

$$w'_{ij} = \sum_{i=1}^{k} W_{P_i}\tilde{w}_{ij} = \left\langle \left( \sum_{i=1}^{k} W_{P_i}\underline{w}_{ij}, \sum_{i=1}^{k} W_{P_i}w_{ij}, \sum_{i=1}^{k} W_{P_i}\bar{w}_{ij} \right); \frac{\sum_{i=1}^{k} A_i \mu_{w_{ij}}}{\sum_{i=1}^{k} A_i}, \frac{\sum_{i=1}^{k} A_i v_{w_{ij}}}{\sum_{i=1}^{k} A_i} \right\rangle, \tag{13}$$

where $A_i = W_{P_i}\frac{|\underline{a}_i| + 2|a_i| + |\bar{a}_i|}{4}$, $i = 1, 2, \dots, k$.

Group decision matrix and criteria weight is obtained as follows:

$$X_k = \tilde{X}_{ij}^k = \begin{bmatrix} \tilde{a}'_{11} & \tilde{a}'_{12} & \cdots & \tilde{a}'_{1n} \\ \tilde{a}'_{21} & \tilde{a}'_{22} & \dots & \tilde{a}'_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}'_{m1} & \tilde{a}'_{m2} & \dots & \tilde{a}'_{mn} \end{bmatrix}, \tag{14}$$

where $i = 1, 2, \dots, k$;

$$w = \left(w'_1, w'_2, \dots, w'_n\right) \qquad \sum_{i=1}^{n} w_i = 1. \tag{15}$$

*Step 3* Normalized triangular intuitionistic fuzzy decision matrices. To eliminate the influence of different dimensions on the decision results, the following formula is employed to address the process of normalization:

$$r_{ij} = \left\langle \left( \frac{\underline{a}_{ij}}{\bar{a}_j^+}, \frac{a_{ij}}{\bar{a}_j^+}, \frac{\bar{a}_{ij}}{\bar{a}_j^+} \right); \frac{\sum_{i=1}^{k} A_i u_{\tilde{a}_{ij}}}{\sum_{i=1}^{k} A_i}, \frac{\sum_{i=1}^{k} A_i v_{\tilde{a}_{ij}}}{\sum_{i=1}^{k} A_i} \right\rangle \tag{16}$$

where $i = 1, 2, \dots, m; j \in B$

$$r_{ij} = \left\langle \left( \frac{\bar{a}_j^-}{\underline{a}_{ij}}, \frac{\bar{a}_j^-}{a_{ij}}, \frac{\bar{a}_j^-}{\bar{a}_{ij}} \right); \frac{\sum_{i=1}^{k} A_i u_{\tilde{a}_i}}{\sum_{i=1}^{k} A_i}, \frac{\sum_{i=1}^{k} A_i v_{\tilde{a}_i}}{\sum_{i=1}^{k} A_i} \right\rangle \tag{17}$$

where $i = 1, 2, \dots, m$; $j \in C$.

Here, $B$ and $C$, respectively, represent benefit criteria and cost criteria; alternatively, $\bar{a}_j^+ = \max\left\{\bar{a}_{ij}\right\}(j \in B)$ and $\bar{a}_j^- = \min\left\{\underline{a}_{ij}\right\}(j \in C)$.

Normalized group decision matrix is expressed as follows:

$$\tilde{M}_j = \begin{bmatrix} M_{11} & M_{12} & \cdots & M_{1n} \\ M_{21} & M_{22} & \cdots & M_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ M_{m1} & M_{m2} & \cdots & M_{mn} \end{bmatrix}, \tag{18}$$

where $i = 1, 2, \dots, m, j = 1, 2, \dots, n$.

*Step 4* Triangular intuitionistic fuzzy numbers matrix is transformed into classical values matrix $\tilde{R}_j$ in virtue of Eq. (9):

$$\tilde{R}_j = \tilde{r}_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}, \tag{19}$$

where $j = 1, 2, \dots, n$.

*Step 5* Construct advantage relations. For a criterion $C_j$, the criteria $J$ set satisfying $\tilde{r}_{ij} > \tilde{r}_{kj}$ is defined as $J^+\left(\tilde{r}_{ij} > \tilde{r}_{kj}\right)$:

$$J^+\left(\tilde{r}_{ij} > \tilde{r}_{kj}\right) = \left\{ j | 1 \le j \le n,\ C_j\left(\tilde{r}_{ij}\right) > C_j\left(\tilde{r}_{kj}\right) \right\}. \tag{20}$$

Similarly, the criteria set satisfying $\tilde{r}_{ij} < \tilde{r}_{kj}$ is expressed as $J^+\left(\tilde{r}_{ij} < \tilde{r}_{kj}\right)$:

$$J^+\left(\tilde{r}_{ij} < \tilde{r}_{kj}\right) = \left\{ j | 1 \le j \le n,\ C_j\left(\tilde{r}_{ij}\right) < C_j\left(\tilde{r}_{kj}\right) \right\}. \tag{21}$$

The criteria set satisfying $\tilde{r}_{ij} = \tilde{r}_{kj}$ is denoted as $J^{+}(\tilde{r}_{ij} = \tilde{r}_{kj})$:

$$J^{+}(\tilde{r}_{ij} = \tilde{r}_{kj}) = \{j|1 \le j \le n,\, C_j(\tilde{r}_{ij}) = C_j(\tilde{r}_{kj})\}. \tag{22}$$

*Step 6* Perform harmony test. The concordance test of $\tilde{C}_{ik}$ as a harmony index, it means the proportion of weights of criterias on $C_j$ as regard for which $S_j$ is not inferior to $S_k$ to weights of all criteria. $\tilde{G}_{ik}$.represents the ratio between weights of criterias where alternative $i$ is not inferior to alternative $k$ and the weights of criteria where alternative $i$ is inferior to alternative $k$.

$$\tilde{C}_{ik} = \frac{\sum_{j\in J^{+}} w_j + \sum_{j\in J^{=}} w_j}{\sum_{j=1}^{n} w_j} \tag{23}$$

$$\tilde{G}_{ik} = \frac{\sum_{j\in J^{+}} w_j + \sum_{j\in J^{=}} w_j}{\sum_{j\in J^{-}}^{n} w_j}. \tag{24}$$

A threshold α is selected, if $\tilde{C}_{ik} \ge \alpha$ and $\tilde{G}_{ik} \ge 1$, then via harmony test.

*Step 7* Perform non- harmony test. The fuzzy non-harmonic test is based on the partial compensability of the criteria, that is, conditional compensability. In the actual decision-making problem, decision makers often not admit that $i$ is generally better than $k$ because $i$ is inferior to $k$ for a criterion. Therefore, the compensation should be limited between the various criteria:

$$\tilde{D}(i,k) = \begin{cases} 0, & \text{if } r_{ij} \ge r_{kj}, \forall j \\ \frac{\max_{j\in J^{-}} |r_{kj}-r_{ij}|}{\delta}, & \text{else} \end{cases}. \tag{25}$$

Here, $\delta$ makes harmony index be normalized and $\delta = \max_{j\in J}\left|r_{ij} - r_{kj}\right|$. For the index of non-harmony, a threshold $d$ is similarly defined. If the non-harmony beyond the value, then alternative $i$ is not superior to alternative $k$ regardless of $i$ performing better in other criteria.

*Step 8* Determine the relationship matrix of outranking relation. The consistency comparison matrix is established according to Eqs. (23–25):

$$S = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1m} \\ s_{21} & s_{22} & \cdots & s_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ s_{m1} & s_{m2} & \cdots & s_{mm} \end{bmatrix}. \tag{26}$$

*Step 9* Rank all the alternatives $A_i (i = 1, 2, \dots, m)$ and select the best one(s) in accordance with the matrix $S$.

# 5 Selection of emergency evacuation strategy in metro station based on the ELECTRE method: taking Guanggu metro in Wuhan as an example

## 5.1 Selection of emergency evacuation strategy based on the ELECTRE method

Wuhan is a central city in central region connecting nine provinces, where constructing urban rail transit is in full swing. Wuhan metro line is expected reach 32 in 2049 and the total length is nearly 1200 km. At present, 1, 2, 3, 4, 6 metro lines have been in operation which about 200 million passengers in daily rail transit network. Guanggu Square metro station is the terminus of Wuhan Metro Line 2 and the total station length reaches 278.7 ms with a total construction area of about 13021.4 sq. m. This station includes the underground island two-story station, where underground-1 is the station floor and underground-2 is the platform layer. There are four entrances and exits and a reserved one. Due to the limitations of the current space and a large amount of passengers, it is easy to make stampede happen in Guanggu Square station. Assuming that fire accident happens in Guanggu Square station, urgent evacuation should be implemented. An expert group immediately is constructed to discuss selecting appropriate evacuation strategies. The expert group is composed of the director of the city traffic committee ($D_1$), station master ($D_2$), the fire brigade captain ($D_3$), and the evacuation organizer ($D_4$). The evaluation

**Table 2** Evaluation matrices of four experts

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $D_1$ | | | | | |
| $S_1$ | G | M | VG | M | VG |
| $S_2$ | M | VG | VP | G | M |
| $S_3$ | G | VG | G | M | M |
| $S_4$ | P | M | M | G | VG |
| $D_2$ | | | | | |
| $S_1$ | M | P | G | G | M |
| $S_2$ | G | G | M | M | P |
| $S_3$ | M | M | P | G | G |
| $S_4$ | M | G | G | P | M |
| $D_3$ | | | | | |
| $S_1$ | M | VP | VG | M | G |
| $S_2$ | M | VG | VP | VG | M |
| $S_3$ | G | G | P | VG | M |
| $S_4$ | G | M | P | M | G |
| $D_4$ | | | | | |
| $S_1$ | G | P | M | VG | M |
| $S_2$ | VG | M | P | M | P |
| $S_3$ | M | M | M | M | M |
| $S_4$ | P | G | M | G | VG |

strategies include $S = \{S_1, S_2, S_3, S_4\}$. In view of the event of fire accident in Guanggu metro station, the evaluation index is set including the matching degree of evacuation equipment ($C_1$), the evacuation capacity of the metro station ($C_2$), the heterogeneity of the evacuation population ($C_3$), the destructive degree of the emergency ($C_4$), and the speed of station emergency response ($C_5$). The specific decision-making process is shown as follows:

1. The members of expert group evaluate, respectively, the evacuation strategy and adopt the fuzzy semantic variables to describe the weight of the index and the weight value. In addition, the evaluation matrices are obtained (Tables 2, 3), where each expert weight value is $W_P = (0.2, 0.25, 0.4, 0.15)$.
2. According to Eqs. (12, 13), the group decision matrix and criteria are determined as shown in Tables 2 and 3:

$$X^k = \begin{bmatrix} \langle(0.370, 0.588, 0.805);0.519, 0.200\rangle & \langle(0.060, 0.200, 0.460);0.387, 0.227\rangle & \langle(0.550, 0.813, 0.955);0.559, 0.200\rangle & \langle(0.450, 0.688, 0.880);0.519, 0.200\rangle & \langle(0.380, 0.600, 0.820);0.382, 0.364\rangle \\ \langle(0.410, 0.638, 0.820);0.408, 0.292\rangle & \langle(0.590, 0.863, 0.955);0.351, 0.300\rangle & \langle(0.135, 0.263, 0.510));0.397, 0.275\rangle & \langle(0.460, 0.700, 0.820);0.519, 0.200\rangle & \langle(0.120, 0.350, 0.580);0.431, 0.294\rangle \\ \langle(0.420, 0.650, 0.880);0.462, 0.335\rangle & \langle(0.460, 0.700, 0.880);0.474, 0.309\rangle & \langle(0.045, 0.288, 0.530);0.419, 0.342\rangle & \langle(0.550, 0.813, 0.955);0.519, 0.200\rangle & \langle(0.390, 0.613, 0.835);0.376, 0.271\rangle \\ \langle(0.275, 0.513, 0.750);0.434, 0.244\rangle & \langle(0.380, 0.600, 0.820);0.448, 0.304\rangle & \langle(0.270, 0.513, 0.755);0.414, 0.259\rangle & \langle(0.195, 0.425, 0.655);0.255, 0.521\rangle & \langle(0.440, 0.675, 0.865);0.301, 0.376\rangle \end{bmatrix}$$

$$w = \begin{bmatrix} (\langle 0.440, 0.675, 0.835\rangle, 0.249, 0.222) \\ (\langle 0.305, 0.475, 0.720\rangle, 0.241, 0.289) \\ (\langle 0.510, 0.763, 0.955\rangle, 0.258, 0.271) \\ (\langle 0.270, 0.438, 0.665\rangle, 0.216, 0.275) \end{bmatrix}.$$

3. The triangular intuitionistic fuzzy decision matrix is normalized in virtue of Eqs. (16, 17):

$$\tilde{M} = \begin{bmatrix} \langle(0.420, 0.668, 0.915);0.519, 0.200\rangle & \langle(0.063, 0.209, 0.482);0.387, 0.227\rangle & \langle(0.082, 0.055, 0.047);0.559, 0.200\rangle & \langle(0.433, 0.284, 0.222);0.519, 0.200\rangle & \langle(0.439, 0.694, 0.948);0.382, 0.364\rangle \\ \langle(0.466, 0.724, 0.932);0.408, 0.292\rangle & \langle(0.618, 0.903, 1.000);0.351, 0.300\rangle & \langle(0.333, 0.171, 0.088);0.397, 0.275\rangle & \langle(0.424, 0.279, 0.238);0.519, 0.200\rangle & \langle(0.139, 0.405, 0.671);0.431, 0.294\rangle \\ \langle(0.477, 0.739, 1.000);0.462, 0.335\rangle & \langle(0.482, 0.733, 0.921);0.474, 0.309\rangle & \langle(1.000, 0.157, 0.085);0.419, 0.342\rangle & \langle(0.355, 0.240, 0.204);0.519, 0.200\rangle & \langle(0.451, 0.708, 0.965);0.376, 0.271\rangle \\ \langle(0.313, 0.582, 0.582);0.434, 0.244\rangle & \langle(0.398, 0.628, 0.859);0.448, 0.304\rangle & \langle(0.167, 0.088, 0.060);0.414, 0.259\rangle & \langle(1.000, 0.459, 0.298);0.255, 0.521\rangle & \langle(0.509, 0.780, 1.000);0.301, 0.376\rangle \end{bmatrix}.$$

**Table 3** Evaluation matrix of criteria weight

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $D_1$ | H | L | M | VH | VL |
| $D_2$ | VH | M | VL | H | M |
| $D_3$ | M | H | H | H | M |
| $D_4$ | M | H | M | M | H |

4. The triangular intuitionistic fuzzy number is transformed into a classic value according to Eq. (9):

$$\tilde{R} = \begin{bmatrix} 0.380 & 0.063 & -0.410 & 0.055 & 0.361 \\ 0.362 & 0.504 & 0.781 & -0.051 & 0.133 \\ 0.402 & 0.459 & 0.589 & -1.701 & 0.424 \\ 0.207 & 0.379 & 0.466 & 0.418 & 0.366 \end{bmatrix}.$$

Similarly, the criteria weight is calculated as $W_c = (0.157, 0.219, 0.216, 0.270, 0.138)$

**Table 4** Advantages relationship

| Advantages relationship | $J^{+}, J^{=}$ | $J^{-}$ |
|---|---|---|
| $s_1 \succ s_2$ | $C_1, C_4, C_5$ | $C_2, C_3$ |
| $s_1 \succ s_3$ | $C_2, C_4$ | $C_1, C_3, C_5$ |
| $S_1 \succ S_4$ | $C_1$ | $C_2, C_3, C_4, C_5$ |
| $s_2 \succ s_3$ | $C_2, C_3, C_4$ | $C_1, C_5$ |
| $s_2 \succ s_4$ | $C_1, C_2, C_3$ | $C_4, C_5$ |
| $s_3 \succ s_4$ | $C_1, C_2, C_3, C_5$ | $C_4$ |

5. The advantages relationship is constructed under the circumstance of the level higher than based on Eqs, (23–25) as shown in Table 4:
6. According to Eqs. (23–24), the consistency judgment matrix is calculated as follows, and a threshold α is selected, if $\alpha = 0.25$ and $\tilde{G}_{ik} \geq 1$, then via harmony test.

$$C = \begin{pmatrix} - & 0.565 & 0.270 & 0.157 \\ 0.435 & - & 0.705 & 0.592 \\ 0.730 & 0.295 & - & 0.730 \\ 0.843 & 0.408 & 0.270 & - \end{pmatrix},$$

$$G = \begin{pmatrix} - & 1.299 & 0.370 & 0.186 \\ 0.770 & - & 2.390 & 1.451 \\ 2.704 & 0.418 & - & 2.704 \\ 5.369 & 0.689 & 0.370 & - \end{pmatrix}.$$

7. According to Eq. (25), the non- harmony test judgment matrix is calculated as follows:

$$D = \begin{pmatrix} 0 & -0.191 & -1 & -0.197 \\ & 0 & -1 & -0.673 \\ & & 0 & -0.092 \\ & & & 0 \end{pmatrix},$$

where $\delta = 2.12$, $D \leq -0.21$.

8. Determine the relationship matrix of outranking relation. The consistency comparison matrix is established according to Eqs. (23–25)

$$S = \begin{pmatrix} 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{pmatrix}.$$

9. The ranking result is expressed as follows:

$S_3 \succ S_1 \succ S_2 \succ S_4$.

In summary, $S_3$ evacuation strategy is selected to quickly organize the Guanggu Square metro station evacuation.

## 5.2 Comparisons and discussion

The technique for order preference by similarity to ideal solution (TOPSIS) is a popular method, which has been extensively researched (Lee and Chen 2008; Chen and Hong 2014; Chen et al. 2016; Wang and Chen 2017; Kuo 2017). In addition, the DEMATEL–MABAC is a new approach which is proposed by Pamučar and Ćirović (2015). In what follows, we compare the proposed method with the TOPSIS (Kuo 2017) and DEMATEL–MABAC (Dragan and Goran 2015) methods. Kuo (2017) proposed a modified TOPSIS with a different ranking index, which considered of the weights of separations of an alternative from the positive ideal solution (PIS) and the negative ideal solution (NIS). The new ranking index was denoted by Kuo (2017) as shown in Eq. (27).

$$\mathrm{RC}_i = w^{+}\left(\frac{D_i^{-}}{\sum_{i=1}^{m} D_i^{-}}\right) - w^{-}\left(\frac{D_i^{+}}{\sum_{i=1}^{m} D_i^{+}}\right), \tag{27}$$

where $w^{+}$ and $w^{-}$ denote the weights of the "cost" criterion and the "benefit"criterion respectively, and $D_i^{+}$ and $D_i^{-}$ represent the distant of alternative $i$ to the PIS and NIS, respectively.

Dragan and Goran (2015) carried out a new multi-criteria method—the DEMATEL–MABAC method, which is based on the distance of the criterion function of each alternative from the border approximation area.

The TOPSIS and MABAC methods are tested under the same conditions, and the results are shown in Table 5.

From Table 5, it is obvious that three methods have the same ranking results. This verifies that the method we proposed is reasonable and validity in this study.

1. Compared with the modified TOPSIS approach which was proposed by Kuo (2017). The main advantage in this paper is that we not only consider the preference of DMs, the outranking relation between criteria is also taken into account, while Kuo's ranking method, modifying the ranking index by adding the DMs preference weight of PIS and NIS which may be difficult to the DMs to determine their preference objectively. In addition, our method makes full use of weights information to characterize the interrelationships among the criteria,

**Table 5** Comparisons with TOPSIS (Kuo 2017) and MABAC (Dragan and Goran, 2015) methods

| Methods | Order of alternatives |
|---|---|
| The proposed method | $S_3 \succ S_1 \succ S_2 \succ S_4$ |
| TOPSIS | $S_3 \succ S_1 \succ S_2 \succ S_4$ |
| MABAC | $S_3 \succ S_1 \succ S_2 \succ S_4$ |

which ensures that the ranking results are more objective and accurate.

2. Compared with the MABAC method which was proposed by Dragan and Goran (2015). The computational complexity of our method is lower than Dragan and Goran's method. The process of implementing the MABAC approach should consider six steps at less, which is not including the steps of the modified fuzzy DEMATEL method. The approach in this paper is a constructive method, which only needs to standard the origin matrix and ranking the alternatives by the classical ELECTRE method.

According to the comparisons and analysis above, the method we proposed is reasonable and validity and is better than the other two methods. Therefore, our method is a good approach to solve intuitionistic fuzzy multiple criteria group decision-making.

## 6 Conclusions

This paper shows that the metro station is a dense place. It is very meaningful to select a suitable evacuation strategy under emergency context, which can shorten the evacuation time, reducing the casualties, and property losses. The conceptual model and algorithm for emergency evacuation strategy selection is constructed based on the ELECTRE approach.

There are some contributions to the current study on the emergency management of metro station in emergency context. First, this paper constructs a conceptual model of the emergency evacuation strategy selection in the metro station under emergency context, and a complete theoretical framework is established. Second, the expert group expresses their evaluation using linguistic fuzzy variables, which are transformed into triangular intuitionistic fuzzy number. In addition, the decision-making attitude of expert group is described from the three dimensions of membership degree, non-membership degree, and hesitation degree, which is close to reality. In summary, this paper is of important theoretical and practical significance.

There are some deficiencies in this study, such as neglecting the effects of experts' communication, risk preference, and the cooperation degrees during the evacuation decision-making in the emergency context of metro station. In the future work, we will remedy defects and extend different decision approaches to the emergency decision area and solve emergency decision-making problem. Furthermore, the study could be continued with anticipation that the method could be found applicable to metro station decision problem, such as metro address selection, planning and designing the route for emergency evacuation, and emergency evacuation evaluation.

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