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An Approach for Evaluating Website Quality in Hotel Industry Based on Triangular Intuitionistic Fuzzy Numbers

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Abstract. Compared to fuzzy numbers, intuitionistic fuzzy numbers provide greater opportunities for solving complex decision-making problems, especially when they are related to ambiguities, uncertainties and vagueness. However, their use is more complex, especially when it comes to ordinary users. Therefore, in this paper an approach adopted for evaluating alternatives on the basis of a smaller number of some more complex evaluation criteria is proposed. The approach is based on the use of linguistic variables, triangular intuitionistic fuzzy numbers, and the Hamming distance. At the end, a case study of hotels' websites evaluation is given to demonstrate the practicality and effectiveness of the proposed approach, together with its limitations and weaknesses. Additionally, a new procedure for ranking intuitionistic fuzzy numbers is proposed and its use is verified.

Key words: intuitionistic fuzzy sets, triangular intuitionistic fuzzy number, aggregation operator, hamming distance, hotel website evaluation.

Introduction

Internet has become a platform for companies in the travel and tourism industry to bring their products and services to the potential customers around the world in a direct, efficient and cost-minimizing way (Lu *et al.*, 2007), therefore, hotel industry and tourism in general is accepting the use of Internet and websites to promote their products and services all over the world. Stetic (2003) in the strategy of development and placement of tourist destination notes that strategy of presenting a tourist destination must be partly based on the use of

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website, i.e. to create a web based strategy in a way that will make a tourist destination desirable to visitors. So it is evident that a number of local communities, with previously less developed hotel industries, are trying to promote tourism potentials in their areas. The Internet, as mentioned, has brought almost unlimited possibilities for promotions, and thus initiated significant changes in the hotel industry. Therefore, the hotel's website has become an important tool in the hotel business. And not only that, the quality of the website has become an important tool for acquiring new customers. This is confirmed by a number of actual researches, such as: Stanujkic *et al*. (2012, 2015), Poklepovic *et al*. (2013), Law *et al*. (2010), Spremic and Strugar (2008), Bai *et al.* (2008), Zafiropoulos and Vrana (2006), Morrison *et al*. (1999, 2005) and Lu *et al*. (2002). An extensive review of the literature on tourism, as well as hotel industry, is given by Hashemkhani Zolfani *et al*. (2015).

Multiple Criteria Decision Making (MCDM) is one of the most important and fastest growing subfields of operational research. As a result of rapid development many MCDM methods have been proposed, such as: SAW AHP, TOPSIS, PROMETHEE, ELECTRE, TODIM, LINMAP, COPRAS, VIKOR, placeARAS, MOORA, MULTIMOORA, WASPAS, SWARA, KEMIRA, EDAS, FARE and so on. A comprehensive owerview of these methods, as well as their application, is given by: Kahraman *et al*. (2015), Mardani *et al*. (2015a, 2015b, 2015c), Zavadskas *et al*. (2014), Zavadskas and Turskis (2011).

The above mentioned MCDM methods, as well as many other similar methods, have been successfully used to solve a number of decision-making problems. However, in the real world many decision-making problems take place in the environments that are associated with some kinds of predictions, uncertainties and ambiguities.

A significant progress in solving real-world decision-making problems appeared after Zadeh (1965) had introduced the Fuzzy Sets (FSs) theory. Based on the FSs theory, Bellman and Zadeh (1970) introduced the Fuzzy Multiple Criteria Decision-Making (FMCDM) methodology, which was subsequently widely accepted and used in solving many decision-making problems.

Using the FSs theory also as a basis, Atanassov (1986, 1999) introduced the Intuitionistic fuzzy sets (IFSs) theory, as an extension of the FSs theory. In addition to belonging to a set, as proposed in the FSs theory, the IFSs theory additionally introduces the concept of not belonging to a set, and therefore it has become very suitable for dealing with imprecise, incomplete, uncertain and vague information, as well as complex MCDM problems.

Numerous studies confirm the applicability and significance of IFSs. Some of these studies are mentioned in Table 1.

These studies were mainly devoted to the consideration of the use and effects obtained on the basis of the use of IFSs in solving MCDM problems, as well as proposing extensions of some prominent MCDM methods capable to deal with IFSs. Literature also identifies some other approaches that consider many other aspects related to the use of IFSs, such as: Zhou and He (2014), Seikh *et al*. (2013), Wu and Cao (2013), Zhang and Liu (2010), Xu and Yager (2008), Mitchell (2004).

However, the number of papers that consider the use of IFSs theory is evidently smaller than the number of papers that consider the use of FSs theory; the same goes for the very

Table 1
Recent researches that confirm the applicability and significance of IFSs.

Considered problems	Authors
Pattern recognition problems	Meng and Chen (2016)
Bridge risk assessment	Shen *et al*. (2016)
Ranking investment alternatives	Zavadskas *et al*. (2015), Hashemkhani Zolfani *et al*. (2015), Zavadskas *et al*. (2014), Razavi Hajiagha *et al*. (2013b)
Air-condition system selection	Hashemkhani Zolfani *et al*. (2015), Liu and Wang (2007), Lin *et al*. (2007)
Tourism management	Chu and Guo (2015)
Revitalization of buildings	Zavadskas *et al*. (2014)
Customer satisfaction determination	Razavi Hajiagha *et al*. (2013a)
Personnel selection	Wan *et al*. (2013)
Medical diagnosis	Chen (2015), De *et al*. (2001)

significant extensions of the IFSs theory: interval-valued fuzzy sets theory and interval-valued intuitionistic fuzzy sets theory. Therefore, this paper aims to draw attention to the importance of IFSs, with the particular emphasis on the benefits that can be achieved based on the use of IFSs in solving complex decision-making problems in environments characterized by ambiguity, uncertainty and vagueness. This paper especially stands out the use of a smaller number of more complex criteria used for evaluation of alternatives, with the aim to compensate higher complexity of criteria by using IFSs.

In addition, the Ranking of Intuitionistic Fuzzy Numbers (IFNs) is much more complex compared to the ranking of ordinary FNs or crisp numbers. Therefore, the number of approaches proposed for ranking IFNs is significantly lower compared to the number of approaches proposed for ranking ordinary FNs. As typical approaches proposed for ranking IFNs can be mentioned the following:

– approaches based on the use of the Score and the Accuracy functions, such as: Xu (2007), Xu and Chen (2007), and Ye (2009); and
– approaches based on the distances from the ideal and anti-ideal solutions, similarly to the approach proposed in ordinary TOPSIS method, such as: Ashtiani *et al.* (2009), Boran *et al.* (2009), and Wang *et al*. (2011).

In this manuscript, an approach based on the use of Hamming distance is proposed. This approach can be seen as a simplified approach discussed in Ashtiani *et al.* (2009), Boran *et al.* (2009), and Wang *et al*. (2011).

Therefore, the rest of this manuscript is organized as follows: Section 1 presents some basic elements necessary to propose a decision-making approach which will enable the use of Intuitionistic Fuzzy Numbers (IFNs). Section 2 and Section 3 consider some procedures for ranking IFNs and linguistic variables adapted for usage with IFNs. Section 4 proposes a framework for evaluating alternatives based on the use of IFNs and linguistic variables, and in Section 5, a case study is considered in order to realistically present applicability and effectiveness of the proposed framework. Finally, the conclusions are given.

1. Preliminaries

This section discusses some parts of FSs theory, IFSs theory, weighted averaging operators, and a group decision-making approach, which are necessary if an approach that enables the use of IF is to be proposed.

1.1. *Some Basic Concepts Related to Intuitionistic Fuzzy Sets*

In contrast to the classical set theory, where an element belongs or does not belong to a set, the FSs theory, introduced by Zadeh (1965), allows partial membership in the set. Let X be universe of discourse. Then a fuzzy set $\tilde{A}$ can be defined as follows:

$$\tilde{A} = \{\langle x, \mu_A(x)\rangle \mid x \in X\}, \tag{1}$$

where: $\mu_A : X \to [0, 1]$ is a membership function, and $\mu_A(x)$ denotes the degree of membership of the element x to the set $\tilde{A}$ (Zadeh, 1965).

In addition to belonging to a set, in IFSs theory Atanassov (1986) also introduced not-belonging to a set. Therefore, an intuitionistic fuzzy set $\tilde{A}$ in X can be defined as follows:

$$\tilde{A} = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in X\}, \tag{2}$$

where: $\mu_A(x)$ and $\nu_A(x)$ denote the degree of membership and the degree of non-membership of the element x to the set A, respectively; $\mu_A : X \to [0, 1]$ and $\nu_A : X \to [0, 1]$, with the following condition

$$0 \leqslant \mu_A(x) + \nu_A(x) \leqslant 1. \tag{3}$$

For each IFS $\tilde{A}$ in X, the amount:

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x) \tag{4}$$

is called the degree of indeterminacy of x to $\tilde{A}$.

Basic arithmetic operations on IFSs. The operations of addition and multiplication on IFSs have been defined by Atanassov (1994). Let $\tilde{A} = \langle\mu_A, \nu_A\rangle$ and $\tilde{B} = \langle\mu_B, \nu_B\rangle$ be two IFSs. Then, the basic arithmetic operations can be defined as follows:

$$\tilde{A} + \tilde{B} = \langle\mu_A + \mu_B - \mu_A\mu_B, \nu_A\nu_B\rangle, \tag{5}$$

$$\tilde{A} \cdot \tilde{B} = \langle\mu_A\mu_B, \nu_A + \nu_B - \nu_A\nu_B\rangle. \tag{6}$$

Score function and accuracy function of IFSs. Let $\tilde{A} = \langle\mu_A, \nu_A\rangle$ be an IFS. The Score $S_{\tilde{A}}$ (Chen and Tan, 1994) and Accuracy $H_{\tilde{A}}$ (Hong and Choi, 2000) function of $\tilde{A}$, respectively, are as follows:

$$S_{\tilde{A}} = \mu_A - \nu_A, \tag{7}$$

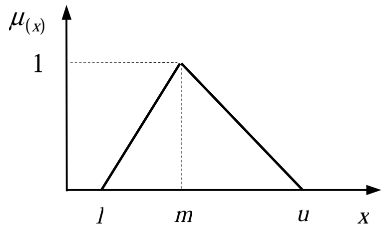

Fig. 1. Triangular fuzzy number.

$$H_{\tilde{A}} = \mu_A + \nu_A, \tag{8}$$

where: $S_{\tilde{A}} \in [-1, 1]$ and $H_{\tilde{A}} \in [0, 1]$.

Hamming distance of IFSs. Let $\tilde{A} = \langle \mu_A, \nu_A \rangle$ and $\tilde{B} = \langle \mu_B, \nu_B \rangle$ be two IFSs. The Hamming distance $d_H(\tilde{A}, \tilde{B})$ and the normalized Hamming distance $d'_H(\tilde{A}, \tilde{B})$ between two IFSs are as follows:

$$d_H(\tilde{A}, \tilde{B}) = \big(|\mu_A - \mu_B| + |\nu_A - \nu_B|\big). \tag{9}$$

Intuitionistic fuzzy weighted averaging operator. Let $\tilde{A}_j = \langle \mu_{A_j}, \nu_{A_j} \rangle$ be a collection of IFSs. The Intuitionistic Fuzzy Weighted Averaging (IFWA) operator of dimensions n is a mapping $IFWA : R^n \to R$ that has an associated weighting vector $W = (w_1, w_2, \ldots, w_n)^T$ with $w_j \in [0, 1]$ and $\sum_{j=1}^{n} w_j = 1$, was defined as Xu (2010, 2007):

$$IFWA(\tilde{A}_1, \tilde{A}_2, \ldots, \tilde{A}_n) = \left\langle 1 - \prod_{j=1}^{n} (1 - \nu_{A_j})^{w_j}, \prod_{j=1}^{n} \mu_{A_j}^{w_j}, \right\rangle. \tag{10}$$

1.2. *Triangular Intuitionistic Fuzzy Numbers*

The Triangular Fuzzy Numbers (TFNs) have been successfully used to solve many complex decision-making problems. A typical TFN, $\tilde{A} = (l, m, u)$, shown in Fig. 1, is fully characterized by a triplet of real numbers (l, m, u), where parameters l, m, and u, indicate the smallest possible value, the most promising value – often called mode or core, and the largest possible value that describe a fuzzy event (Stanujkic, 2013; Ertugrul and Karakasoglu, 2009; Dubois and Prade, 1980).

The membership function of TFNs is defined as follows:

$$\mu(x) = \begin{cases} 0, & x < l, \\ (x - l)/(m - l), & l \leqslant x \leqslant m, \\ (u - x)/(u - m), & l \leqslant x \leqslant u, \\ 0, & x > u. \end{cases} \tag{11}$$

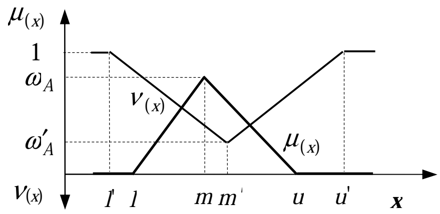

Fig. 2. Triangular IFN.

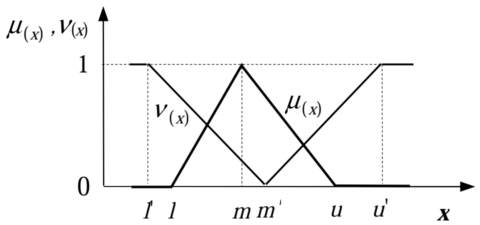

Fig. 3. A normalized TIFN.

The Triangular Intuitionistic Fuzzy Numbers (TIFNs) have been introduced in IFSs theory. A TIFN $\tilde{A}$, $\tilde{A} = \langle(l, m, u; \omega_A), (l', m', u'; \omega'_A)\rangle$, shown in Fig. 2, is defined with its membership function $\mu_A(x)$ and non-membership function $\nu_A(x)$, as follows:

$$\mu(x) = \begin{cases} \omega(x-l)/(m-l), & l \leqslant x < m, \\ \omega, & x = m, \\ \omega(u-x)/(u-m), & m < x \leqslant u, \\ 0, & \text{otherwise}, \end{cases} \tag{12}$$

$$\nu(x) = \begin{cases} [m' - x + \omega'(x-l')]/(m'-l'), & l' \leqslant x \leqslant m', \\ \omega', & x = m', \\ [x - m' + \omega'(u'-x)]/(u'-m'), & m' < x \leqslant u', \\ 1, & \text{otherwise}, \end{cases} \tag{13}$$

where: parameters l, m, and u indicate the smallest possible value, the most promising value and the largest possible value that describe belonging to a set, respectively, parameters l', m', and u' indicate the smallest possible value, the most promising value and the largest possible value that describe not-belonging to a set, ω_A and ω'_A respectively represent the maximum degree of the membership and the non-membership such that $0 \leqslant \omega_A \leqslant 1$, $0 \leqslant \omega'_A \leqslant 1$ and $0 \leqslant \omega_A + \omega'_A \leqslant 1$.

Normalized TIFNs can be mentioned as particular case of the TIFNs, shown in Fig. 3, where $\omega = 1$ and $\omega' = 0$.

Basic arithmetic operations on TIFNs. Let $\tilde{A} = \langle(a_l, a_m, a_u), (a'_l, a'_m, a'_u)\rangle$ and $\tilde{B} = \langle(b_l, b_m, b_u), (b'_l, b'_m, b'_u)\rangle$ be two normalized TIFNs. The operations of addition and multiplication on TIFNs are as follows Zhang and Liu (2010):

$$\tilde{A}+\tilde{B}=\big\langle(a_l+b_l-a_lb_l, a_m+b_m-a_mb_m, a_u+b_u-a_ub_u), \big(a'_lb'_l, a'_mb'_m, a'_ub'_u\big)\big\rangle, \tag{14}$$

$$\tilde{A}\cdot\tilde{B}=\big\langle(a_lb_l, a_mb_m, a_ub_u), \big(a'_l+b'_l-a'_lb'_l, a'_m+b'_m-a'_mb'_m, a'_u+b'_u-a'_ub'_u\big)\big\rangle. \tag{15}$$

Score function and Accuracy function of TIFNs. Let $\tilde{A}=\langle(a_l, a_m, a_u), (a'_l, a'_m, a'_u)\rangle$ be a TIFN. The Score $S_{\tilde{A}}$ and Accuracy $H_{\tilde{A}}$ functions of $\tilde{A}$, respectively, are as follows Zhang and Liu (2010):

$$S_{\tilde{A}}=\frac{1}{3}\big(a_l-a'_l+a_m-a'_m+a_u-a'_u\big), \tag{16}$$

$$H_{\tilde{A}}=\frac{1}{3}\big(a_l+a'_l+a_m+a'_m+a_u+a'_u\big), \tag{17}$$

where: $S_{\tilde{A}}\in[-1,1]$ and $H_{\tilde{A}}\in[0,1]$.

Hamming distance of TIFNs. Let $\tilde{A}=\langle(a_1, a_2, a_3), (a'_1, a'_2, a'_3)\rangle$ and $\tilde{B}=\langle(b_1, b_2, b_3), (b'_1, b'_2, b'_3)\rangle$ be two normalized TIFNs. Then, the Hamming distances are as follows:

$$d_H(\tilde{A},\tilde{B})=\sum_{i=1}^{3}\big(|a_i-b_i|+\big|a'_i-b'_i\big|\big). \tag{18}$$

Triangular intuitionistic fuzzy weighted averaging operator. Let $\tilde{A}_j=\langle(l_j, m_j, u_j), (l'_j, m'_j, u'_j)\rangle$ be a collection of TIFNs. Then, the Triangular Intuitionistic Fuzzy Weighted Averaging (TIFWA) operator of dimensions n, with an associated weighting vector $W=(w_1, w_2, \dots, w_n)^T$, can be shown as follows Wang (2008), Zhang and Liu (2010):

$$\begin{aligned}&\mathit{TIFWA}(\tilde{A}_1, \tilde{A}_2, \dots, \tilde{A}_n)\\&\quad=\left\langle\left(1-\prod_{j=1}^{n}\big(1-l'_j\big)^{w_j}, 1-\prod_{j=1}^{n}\big(1-m'_j\big)^{w_j}, 1-\prod_{j=1}^{n}\big(1-u'_j\big)^{w_j}\right),\right.\\&\qquad\left.\left(\prod_{j=1}^{n}l_j^{w_j}, \prod_{j=1}^{n}m_j^{w_j}, \prod_{j=1}^{n}u_j^{w_j}\right)\right\rangle,\end{aligned} \tag{19}$$

where: $w_j\in[0,1]$ and $\sum_{j=1}^{n}w_j=1$.

2. Procedures for Ranking TIFNs

For the purpose of ranking alternatives, and/or selecting the most appropriate ones, in the MCDM models based on the use of the TIFNs the computational procedures should be able to perform ranking of TIFNs or those TIFNs must be transformed into crisp numbers before ranking.

In this section, three procedures for ranking TIFNs are discussed. The first procedure is proposed by Xu and Yager (2006), and it is based on the use of Score function and Accuracy functions. The second procedure is based on the use of distances from the fuzzy intuitionistic ideal and anti-ideal points, as in the well-known TOPSIS method.

Finally, a new procedure based on the use of Hamming distance from the fuzzy intuitionistic ideal point is proposed in this paper.

In order to facilitate their usage all procedures are adopted to have the same starting point and their usage begins from aggregated interval-valued intuitionistic fuzzy decision matrix.

2.1. *The Procedure for Ranking TIFNs Based on Score Function*

Xu and Yager (2006) proposed a procedure for comparing TIFNs. On this basis, the procedure for ranking TIFNs based on the use of Score function can be precisely defined using the following steps (Procedure I):

Step 1. ***Determine the overall performance ratings for each of considered alternatives.*** The overall triangular intuitionistic fuzzy performance ratings of considered alternatives should be determined by using Eq. (19).

Step 2. ***Determine the Score function for each of considered alternatives.*** In this step, the value of the Score function can be determined by using Eq. (16).

Step 3. ***Rank the alternatives and select the best one.*** In this step, the considered alternatives are ranked in ascending order based on the values of their Score functions. In addition, the alternative with the highest value Score function is the most appropriate alternative.

In other words, a TIFN is ranked higher if the value of its Score function is greater. In the particular cases, when two or more alternatives have the same value of the Score function it is necessary to determine the value of their Accuracy functions, using Eq. (17). In such cases, the alternatives with a higher value of Accuracy function will be ranked higher.

2.2. *The Procedure for Ranking TIFNs Based on the Use of Distances from the Ideal and Anti-Ideal Point*

A significant number of authors extended the concept proposed in TOPSIS method, or more accurately the concept based on the shorter distance from the ideal point and further distance from the anti-ideal point, for the purpose of its usage for ranking TIFNs, such as: Chen and Tsao (2008), Boran *et al.* (2009), Yadav and Kumar (2009), Ye (2010), Park *et al.* (2011).

These procedures are of varying complexity, and also use different distance metrics, usually Euclidean distance. In this paper, one of the simplest, based on Wang *et al.* (2011), is shown as follows (Procedure II):

Step 1. ***Determine an ideal point and anti-ideal point, for each criterion.*** Let be aggregated intuitionistic fuzzy decision matrix, and be the aggregated triangular intuitionistic fuzzy performance rating of alternative i in relation to the criterion j. Then, the triangular intuitionistic fuzzy ideal point and the triangular intuitionistic fuzzy anti-ideal point for criterion j can been determined as follows:

$$\begin{aligned} \tilde{A}_j^* &= \langle (l_j^*, m_j^*, u_j^*), (l_{'j}^*, m_j'^*, u_j'^*) \rangle \\ &= \Big\langle \Big(\max_i l_{ij}, \max_i m_{ij}, \max_i u_{ij} \Big), \Big(\min_i l'_{ij}, \min_i m'_{ij}, \min_i u'_{ij} \Big) \Big\rangle, \end{aligned} \tag{20}$$

$$\begin{aligned} \tilde{A}_j^- &= \langle (l_j^-, m_j^-, u_j^-), (l_{'j}^-, m_j'^-, u_j'^-) \rangle \\ &= \Big\langle \Big(\min_i l_{ij}, \min_i m_{ij}, \min_i u_{ij} \Big), \Big(\max_i l'_{ij}, \max_i m'_{ij}, \max_i u'_{ij} \Big) \Big\rangle. \end{aligned} \tag{21}$$

Step 2. ***Calculate the weighted Hamming distances to the ideal solution and anti-ideal solution***.

The weighted Hamming distances of each alternative to the ideal solution d_i^+ can be determined as follows:

$$\begin{aligned} d_i^+ = \sum_{j=1}^{n} d_H(\tilde{a}_{ij}, \tilde{A}_j^*) w_j &= \sum_{j=1}^{n} \big(|l_{ij} - l_j^*| + |m_{ij} - m_j^*| + |u_{ij} - u_j^*| + |l'_{ij} - l_j'^*| \\ &\quad + |m'_{ij} - m_j'^*| + |u'_{ij} - u_j'^*| \big) w_j, \end{aligned} \tag{22}$$

where w_j is the weight of criterion j.

Similarly, the weighted Hamming distance from anti-ideal solution d_i^-can be determined as follows:

$$\begin{aligned} d_i^- = \sum_{j=1}^{n} d_H(\tilde{a}_{ij}, \tilde{A}_j^-) w_j &= \sum_{j=1}^{n} \big(|l_{ij} - l_j^-| + |m_{ij} - m_j^-| + |u_{ij} - u_j^-| \\ &\quad + |l_{ij} - l_j'^-| + |m_{ij} - m_j'^-| + |u_{ij} - u_j'^-| \big) w_j. \end{aligned} \tag{23}$$

Step 3. ***Calculate the relative closeness to the ideal solution.*** The relative closeness to the ideal solution of alternative i can be calculated as follows:

$$C_i = \frac{d_i^-}{d_i^- + d_i^+}, \tag{24}$$

where C_i denotes relative closeness of alternative i to the ideal solution, and $C_i \in [0, 1]$.

Step 4. ***Rank the alternatives and select the best one.*** In this step, the considered alternatives are ranked in ascending order based on the values of their C_i. In addition, the alternative with the highest value of C_i is the most appropriate alternative.

To use this procedure, it is necessary to construct the aggregated interval-valued intuitionistic fuzzy decision matrix.

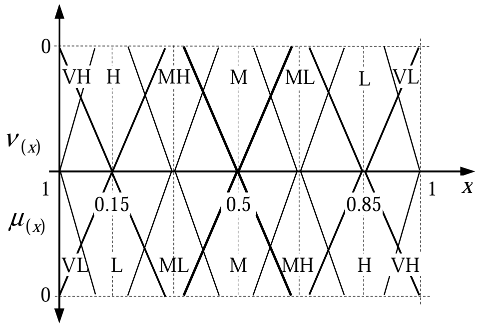

Fig. 4. The membership functions of linguistic variables.

A similar approach is proposed by Yadav and Kumar (2009). However, they use Euclidean distance and ideal and anti-ideal points determined on the basis of an aggregated weighted triangular intuitionistic fuzzy decision matrix, which is why their approach is somewhat more complex.

2.3. *The Procedure for Ranking TIFNs Based on the Use of the Hamming Distance*

The proposed procedure for ranking TIFNs based on the use of Hamming distance from ideal point (Procedure III) can be precisely defined using the following steps:

Step 1. ***Determine an ideal point.*** As in the previous procedure, the triangular intuitionistic fuzzy ideal point $\tilde{A}_j^*$ for each criterion should be determined as follows:

$$\begin{aligned}\tilde{A}_j^* &= \langle (l_j^*, m_j^*, u_j^*), (l_j'^*, m_j'^*, u_j'^*) \rangle \\ &= \Big\langle \Big(\max_i l_{ij}, \max_i m_{ij}, \max_i u_{ij} \Big), \Big(\min_i l'_{ij}, \min_i m'_{ij}, \min_i u'_{ij} \Big) \Big\rangle. \end{aligned} \tag{25}$$

Step 2. ***Determine the weighted Hamming distances between each alternative and the ideal point.*** In this step, the weighted Hamming distance between an alternative and triangular intuitionistic fuzzy ideal point can be determined by using Eq. (22).

Step 3. ***Rank the alternatives and select the best one.*** A smaller distance to the ideal point correlates with the best ranked alternative. Therefore, the alternatives are ranked based on their Hamming distances in descending order, and the alternative with the lowest value of Hamming distances to the ideal point is the most appropriate alternative.

3. Intuitionistic Fuzzy Linguistic Variables

The fuzzy linguistic variable has been extensively used in decision-making, and as a result, numerous linguistic scales (variables) are also proposed. In this approach, the specific linguistic scale adapted for the use of TIFNs, shown in Fig. 4 and Table 2, is proposed.

Table 2
Linguistic variables for expressing satisfaction and dissatisfaction levels.

Linguistic variable	Corresponding triangular fuzzy number	Mode	BNP[a]
Absolutely false (AF)	(0, 0, 0)	0	0.000
Very low (VL)	(0.0, 0.0,0.1)	0	0.033
Low (L)	(0.0, 0.15, 0.3)	0.15	0.150
Moderate low (ML)	(0.2, 0.325, 0.45)	0.325	0.325
Moderate (M)	(0.35, 0.5, 0.65)	0.5	0.500
Moderate high (MH)	(0.5, 0.625, 0.75)	0.625	0.625
High (H)	(0.7, 0.85, 1.0)	0.85	0.850
Very high (VH)	(0.9, 1.0, 1.0)	1	0.967
Absolutely true (AT)	(1.0, 1.0, 1.0)	1	1.000

[a] Best non-fuzzy performance (BNP) value.

Table 3
Acceptable combinations of linguistic variables.

Satisfaction level – affirmative attitude	Dissatisfaction level – disagreement (degree of indeterminacy)[a]							
Absolutely true (AT)	AF (0.00)							
Very high (VH)	VL (0.00)	AF (0.03)						
High (H)	L (0.00)	VL (0.12)	AF (0.15)					
Moderate high (MH)	ML (0.05)	L (0.22)	VL (0.34)	AF (0.38)				
Moderate (M)	M (0.00)	ML (0.18)	L (0.35)	VL (0.47)	AF (0.50)			
Moderate low (ML)	MH (0.05)	M (0.18)	ML (0.35)	L (0.53)	VL (0.64)	AF (0.68)		
Low (L)	H (0.00)	MH (0.23)	M (0.35)	ML (0.53)	L (0.70)	VL (0.82)	AF	
Very low (VL)	VH (0.00)	H (0.12)	MH (0.34)	M (0.47)	ML (0.64)	L (0.82)	VL (0.93)	AF (0.97)
Absolutely false (AF)	AT (0.00)	VH (0.03)	H (0.15)	MH (0.38)	M (0.50)	ML (0.68)	L (0.85)	VL (0.97)

[a] Degree of indeterminacy based on BNP.

In order to satisfy the condition (3), i.e. the condition according to which the degree of indeterminacy should be less than or equal to one, Table 3 shows acceptable combinations of linguistic variables that can be used for expressing satisfaction and dissatisfaction levels.

The degree of indeterminacy of acceptable combination of linguistic variables in Table 3 is determined on the basis of Eq. (4), where BNP of linguistic variable used for expressing the degree of satisfaction level is used instead of $\mu_A(x)$ and BNP of linguistic variable used for expressing the degree of dissatisfaction level is used instead of $v_A(x)$.

4. A Framework for Evaluating Alternatives Based on the Use of TIFNs and Linguistic Variables

A Fuzzy Multiple Criteria Group Decision Making (FMCGDM) model can be shown as follows:

$$\tilde{D} = [\tilde{x}_{ij}^k]_{m \times n \times K}, \tag{26}$$

$$\tilde{W} = [\tilde{w}_j^k]_n, \tag{27}$$

or, when the weights of criteria expressed by using crisp numbers, as:

$$W = [w_j^k]_n, \tag{28}$$

where: $\tilde{D}$ denotes FMCGDM matrix, $\tilde{W}$ and W denotes fuzzy and crisp weighting vector, respectively, $\tilde{x}_{ij}^k$ is the performance rating of alternative i in relation to the criterion j given by the respondent k; $\tilde{w}_j^k$ and w_j^k are fuzzy or crisp weights of criterion j obtained from the respondent k; $i = 1, 2, \dots, m$; m is a number of alternatives, $j = 1, 2, \dots, n$; n is a number of criteria used for evaluation, $k = 1, 2, \dots, K$; K is a number of respondents involved in FMCGDM.

In the case of solving complex real-world MCDM problems, or more precisely solving decision-making problems using FMCGDM extensions of ordinary MCDM methods, different phases can be identified. However, the aim of this paper is not their clear and precise identification, which is why here only some of the most important phases are mentioned in which the use of TIFNs and the use of linguistic variables have an impact, i.e.:

– preparation phase;
– evaluation phase;
– computational and selection phase.

Preparation phase. In the preparatory phase, the respondents involved in evaluation of alternatives are briefly introduced with the meaning of IFSs, especially the TIFNs, and linguistic variables. In this phase, the respondents are also introduced with the benefits that can be obtained on the basis of their usage, especially with the fact that they allow simultaneous expression of the degree of belonging and not belonging to something. And finally, the respondents are allowed to test their skills regarding the practical use of the proposed linguistic variables in several examples after which comes their practical use.

Evaluation phase. In the evaluation phase, respondents are informed in detail about the meaning of criteria, and the relevant sub-criteria that they need to pay attention to during the evaluation of alternatives in relation to the criteria.

After that, using linguistic variables from Table 1, and considering the limitations specified in Table 2, the surveyed respondents express their attitudes.

Computational and selection phase. The computational and selection phase can be precisely defined using the following steps:

Step 1. ***Transform the linguistic variable in the corresponding TIFNs.*** The first step of the computational phase includes the transformation of the previously obtained variables into TIFNs and after that comes the formation of the decision-making matrix (25).

Step 2. ***Determine the group performance rating of each alternative.*** In this step, using the TIFWA operator, i.e. Eq. (18), the group performance ratings of the considered alternatives are determined. As a result of this step the aggregated interval-valued intuitionistic fuzzy decision matrix is formed, as follows

$$\tilde{D} = [\tilde{g}_{ij}]_{m\times n}, \tag{29}$$

where $\tilde{g}_{ij}$ denotes the aggregated triangular intuitionistic fuzzy performance rating of alternative i in relation to the criterion j.

Step 3. ***Rank the alternatives and select the most appropriate one.*** The ranking of considered alternatives and selection of the most appropriate one depends on the procedure used for ranking TIFNs and it can be performed as it is described in the Section 2.

5. A Case Study

The quality of the websites, i.e. the level of website visitors' satisfaction by a particular site, is influenced by numerous parameters, which usually also have different importance (weights). All this points to the complexity of determining the quality of websites, i.e. the complexity of their ranking.

One study, based on Stanujkic *et al.* (2012), is performed to demonstrate the applicability and the efficiency of the proposed approach. On the basis of this study the following hotels have been selected[2]:

- ***The Stara Planina Hotel.*** The Stara Planina hotel (Old Mountain) is placed in the newly opened ski centre, in the mountain bearing the same name. Its website, at first available at http://hotelstaraplanina.com, is now relocated and can be found at the following address: http://www.falkensteiner.com/en/hotel/stara-planina;
- ***The Jezero Hotel.*** The Jezero hotel (Lake hotel), located on the coast of a beautiful reservoir, called Bor Lake. Its website is available at http://www.hoteljezero.rs/; and
- ***The Kastrum Hotel.*** This hotel is located in the well-known, but little utilized Serbian spa known as Gamzigradska Banja (Gamzigrad Spa). There is an archaeological site of an old Roman palace called Felix Romuliana in its vicinity. Today Felix Romuliana is under UNESCO protection because of its historical and cultural importance. The website of the Kastrum Hotel is available at: http://www.hotelkastrum.rs.

The criteria used to evaluate the quality of the hotels' websites, proposed by Law and Cheung (2005), and their weights are shown in Table 4.

[2]Note: The purpose of this study is not to promote any of these hotels. Therefore, the order of the considered alternatives below is not the same as the order of the mentioned hotels. Evaluation of the hotels' websites is done based on the versions available on the 15th May 2014.

Table 4
Criteria and weights for hotels' Websites evaluation.

	Criteria	Weights
C_1	Reservations information	0.22
C_2	Facilities information	0.22
C_3	Contact information	0.21
C_4	Surrounding area information	0.19
C_5	Website management	0.16

Since these criteria are rather complex, Law and Cheung (2005) also identified a number of sub-criteria in order to allow a more accurate evaluation of the hotels' websites. However, the evaluation of alternatives based on the use of a large number of criteria and sub-criteria can be too complex for ordinary user, i.e. respondents.

Therefore, only the above mentioned five criteria were used in the evaluation process in this study. This approach was chosen to allow respondents to pay greater attention to the preference ratings that they awarded to the alternatives than to the selected evaluation criteria. In other words, this approach gives greater preference to the use of a smaller number of criteria and more precisely determined performance ratings than to the use of a larger number of criteria and sub-criteria, whose performance ratings are less precisely determined.

As previously indicated, it is not so easy to precisely determine performance ratings in a fuzzy environment. Therefore, this study adopts a proven approach in which the respondents use linguistic variables to express their performance ratings. These linguistic variables are later transformed into corresponding TIFNs, in one of the next MCDM phases.

Using the procedure described in Section 4, after the introduction, the evaluation phase is carried out as follows:

Reservation information. To evaluate the quality of websites based on the first criterion, reservation information, respondents are asked to pay attention to the information about: room rates, check availability, check in and check out time, online reservations, viewing or cancelling reservations, reservation policies, payment options, security payment systems; and are also asked to share their attitudes, i.e. to state their satisfaction and dissatisfaction levels using the linguistic variables from the proposed linguistic scale. The results of evaluating hotels in relation to reservation information obtained from the three respondents, E_1, E_2 and E_3, are shown in Table 5.

The use of the proposed combinations of linguistic variables from Table 3 can be clearly presented on the basis of evaluation of alternatives A_1 and A_2 based on the opinion of respondent E_3.

The respondent E_3 has used a combination (VH, VL) for the evaluation of alternative A_1, whose degree of indeterminacy is zero, which indicates that the evaluator E_3 has a clear view on the quality of the website denoted as A_1 considered in relation to the criterion C_1, i.e. reservation information.

In the case of evaluating the website designated as A_2 the respondent E_3 uses a combination of linguistic variables (H, VL) whose degree of indeterminacy is greater than 0,

Table 5
The results of ranking hotels in relation to the Reservations information.

Alternatives	E_1		E_2		E_3	
	SF level[a]	DSF level[b]	SF level	DSF level	SF level	DSF level
A_1	VH	VL	VH	VL	VH	VL
A_2	VH	VL	VH	VL	H	VL
A_3	L	H	ML	M	L	MH

[a] Satisfaction level/affirmative attitude.
[b] Dissatisfaction level/disagreement.

Table 6
The results of ranking hotels in relation to the Facilities information.

Alternatives	E_1		E_2		E_3	
	SF level	DSF level	SF level	DSF level	SF level	DSF level
A_1	VH	VL	H	VL	VH	VL
A_2	MH	VL	VH	VL	H	VL
A_3	L	M	L	MH	L	H

Table 7
The results of ranking hotels in relation to the Contact information.

Alternatives	E_1		E_2		E_3	
	SF level	DSF level	SF level	DSF level	SF level	DSF level
A_1	H	L	MH	L	MH	ML
A_2	H	VL	MH	ML	MH	ML
A_3	H	VL	MH	VL	MH	L

or more precisely is 0.12, indicating that he has some doubts regarding the website in relation to the criterion C_1.

Facility information. Regarding the evaluation of the second criterion, i.e. facility information, respondents are asked to pay attention to the information about: hotel location maps, hotel features, photos of hotel features, hotel descriptions, restaurants and virtual tours; and to express their attitudes using the linguistic terms. The obtained results are shown in Table 6.

Contact information. A similar approach is used in evaluating alternatives in relation to the remaining criteria. In the case of contact information criterion, respondents are asked to pay attention to the availability and ease of finding the information about: telephone numbers, addresses, e-mail addresses, fax numbers and contact persons. The obtained results are shown in Table 7.

Surrounding area information. Regarding the evaluation of the surrounding area information criterion, respondents are asked to pay attention to the information about: transportation, airport information, and the main attractions in the nearer cities and surrounding areas. The obtained results are shown in Table 8.

Table 8
The results of ranking hotels in relation to the Surrounding area information.

Alternatives	E_1		E_2		E_3	
	SF level	DSF level	SF level	DSF level	SF level	DSF level
A_1	H	VL	MH	VL	MH	L
A_2	H	VL	MH	ML	MH	ML
A_3	L	VL	L	ML	VL	H

Table 9
The results of ranking hotels in relation to the Website management.

Alternatives	E_1		E_2		E_3	
	SF level	DSF level	SF level	DSF level	SF level	DSF level
A_1	M	ML	ML	M	M	ML
A_2	ML	ML	M	ML	MH	ML
A_3	L	VL	L	ML	VL	MH

Table 10
Performance ratings of hotels' websites presented in the form of TIFNs.

Criteria Alternat		E_1	E_2	E_3
A_1	C_1	⟨(0.9, 1.0, 1.0), (0.0, 0.0, 0.1)⟩	⟨(0.9, 0.9, 0.9), (0.0, 0.0, 0.1)⟩	⟨(0.9, 0.9, 0.9), (0.0, 0.0, 0.1)⟩
	C_2	⟨(0.9, 1.0, 1.0), (0.0, 0.0, 0.1)⟩	⟨(0.7, 0.85, 1.0), (0.0, 0.0, 0.1)⟩	⟨(0.9, 0.9, 0.9), (0.0, 0.0, 0.1)⟩
	C_3	⟨(0.7, 0.85, 1.0), (0.0, 0.15, 0.3)⟩	⟨(0.5, 0.63, 0.75), (0.0, 0.15, 0.3)⟩	⟨(0.5, 0.63, 0.75), (0.2, 0.33, 0.45)⟩
	C_4	⟨(0.7, 0.85, 1.0), (0.0, 0.0, 0.10)⟩	⟨(0.50, 0.63, 0.75), (0.0, 0.0, 0.10)⟩	⟨(0.5, 0.63, 0.75), (0.0, 0.15, 0.30)⟩
	C_5	⟨(0.35, 0.5, 0.65), (0.2, 0.33, 0.45)⟩	⟨(0.2, 0.33, 0.45), (0.35, 0.5, 0.65)⟩	⟨(0.5, 0.63, 0.75), (0.2, 0.33, 0.45)⟩
$A2$	C_1	⟨(0.90, 1.0, 1.0), (0.0, 0.0, 0.10)⟩	⟨(0.9, 0.9, 0.9), (0.0, 0.0, 0.10)⟩	⟨(0.7, 0.85, 1.0), (0.0, 0.0, 0.1)⟩
	C_2	⟨(0.5, 0.63, 0.75), (0.0, 0.0, 0.10)⟩	⟨(0.9, 0.9, 0.9), (0.0, 0.0, 0.10)⟩	⟨(0.7, 0.85, 1.0), (0.0, 0.0, 0.1)⟩
	C_3	⟨(0.7, 0.85, 1.0), (0.0, 0.0, 0.10)⟩	⟨(0.5, 0.63, 0.75), (0.2, 0.33, 0.45)⟩	⟨(0.5, 0.63, 0.75), (0.2, 0.33, 0.45)⟩
	C_4	⟨(0.7, 0.85, 1.0), (0.0, 0.0, 0.10)⟩	⟨(0.5, 0.63, 0.75), (0.2, 0.33, 0.45)⟩	⟨(0.5, 0.63, 0.75), (0.2, 0.33, 0.45)⟩
	C_5	⟨(0.2, 0.33, 0.45), (0.2, 0.33, 0.45)⟩	⟨(0.5, 0.63, 0.75), (0.2, 0.33, 0.45)⟩	⟨(0.5, 0.63, 0.75), (0.2, 0.33, 0.45)⟩
$A3$	C_1	⟨(0.0, 0.15, 0.30), (0.7, 0.85, 1.0)⟩	⟨(0.2, 0.33, 0.45), (0.35, 0.5, 0.65)⟩	⟨(0.0, 0.15, 0.3), (0.5, 0.63, 0.75)⟩
	C_2	⟨(0.0, 0.15, 0.30), (0.35, 0.5, 0.65)⟩	⟨(0.0, 0.15, 0.3), (0.5, 0.63, 0.75)⟩	⟨(0.0, 0.15, 0.3), (0.7, 0.85, 1.0)⟩
	C_3	⟨(0.7, 0.85, 1.0), (0.0, 0.0, 0.1)⟩	⟨(0.5, 0.63, 0.75), (0.0, 0.0, 0.10)⟩	⟨(0.5, 0.63, 0.75), (0.0, 0.15, 0.3)⟩
	C_4	⟨(0.0, 0.15, 0.3), (0.0, 0.0, 0.1)⟩	⟨(0.0, 0.15, 0.3), (0.2, 0.33, 0.45)⟩	⟨(0.0, 0.0, 0.10), (0.7, 0.85, 1.0)⟩
	C_5	⟨(0.0, 0.15, 0.3), (0.0, 0.0, 0.1)⟩	⟨(0.0, 0.15, 0.3), (0.2, 0.33, 0.45)⟩	⟨(0.0, 0.0, 0.10), (0.5, 0.63, 0.75)⟩

Website management. And finally, when evaluating the website management criterion, respondents are asked to pay attention to the information about: up-to-date information on the site, multilingual site, site map, search function, as well as the design and functionality of the website. The obtained results are shown in Table 9.

After evaluating the alternatives in relation to the chosen set of criteria, the previously obtained linguistic variables are transformed into TIFNs in the computational phase, as is shown in Table 10.

In the next step, using the TIFWA, i.e. using Eq. (19), the resulting performance of the considered alternatives is determined. During this transformation the individual performance ratings obtained from respondents, are transformed into the group performance ratings, which is shown in Table 11.

During this transformation, the following weights have been assigned to the respondents: $w_1 = 0.4$, $w_2 = 0.3$ and $w_3 = 0.3$.

Table 11
Group performance ratings of hotels' websites in the form of TIFNs.

Alternatives	Criteria	Interval-valued performance ratings
$A1$	C_1	$\langle(0.90, 1.00, 1.00), (0.00, 0.00, 0.10)\rangle$
	C_2	$\langle(0.86, 1.00, 1.00), (0.00, 0.00, 0.10)\rangle$
	C_3	$\langle(0.59, 0.74, 1.00), (0.00, 0.19, 0.34)\rangle$
	C_4	$\langle(0.59, 0.74, 1.00), (0.00, 0.00, 0.14)\rangle$
	C_5	$\langle(0.36, 0.50, 0.64), (0.24, 0.37, 0.50)\rangle$
$A2$	C_1	$\langle(0.86, 1.00, 1.00), (0.00, 0.00, 0.10)\rangle$
	C_2	$\langle(0.74, 0.81, 1.00), (0.00, 0.00, 0.10)\rangle$
	C_3	$\langle(0.59, 0.74, 1.00), (0.00, 0.00, 0.25)\rangle$
	C_4	$\langle(0.59, 0.74, 1.00), (0.00, 0.00, 0.25)\rangle$
	C_5	$\langle(0.40, 0.53, 0.66), (0.20, 0.33, 0.45)\rangle$
$A3$	C_1	$\langle(0.06, 0.21, 0.35), (0.51, 0.66, 0.81)\rangle$
	C_2	$\langle(0.00, 0.15, 0.30), (0.48, 0.63, 0.77)\rangle$
	C_3	$\langle(0.59, 0.74, 1.00), (0.00, 0.00, 0.14)\rangle$
	C_4	$\langle(0.00, 0.11, 0.25), (0.00, 0.00, 0.31)\rangle$
	C_5	$\langle(0.00, 0.11, 0.25), (0.00, 0.00, 0.29)\rangle$

Table 12
The overall performance ratings in the form of TIFNs.

Alternatives	Interval-valued performance ratings
A_1	$\langle(0.75, 1.00, 1.00), (0.00, 0.00, 0.18)\rangle$
A_2	$\langle(0.69, 1.00, 1.00), (0.00, 0.00, 0.18)\rangle$
A_3	$\langle(0.18, 0.34, 1.00), (0.00, 0.00, 0.39)\rangle$

Table 13
The ranking results obtained on the basic Procedure I.

	Procedure I	
Alternatives	S_i	Rank
A_1	0.856	1
A_2	0.835	2
A_3	0.376	3

Table 14
The ranking results obtained on the basic Procedure II.

A^* alternatives	$\langle(0.75, 1.00, 1.00), (0.00, 0.00, 0.18)\rangle$	d_i^-	d_i^+	d_i	Rank
A_1	$\langle(0.75, 1.00, 1.00), (0.00, 0.00, 0.18)\rangle$	0.00	1.56	0.766	1
A_2	$\langle(0.69, 1.00, 1.00), (0.00, 0.00, 0.18)\rangle$	0.01	1.56	0.764	2
A_3	$\langle(0.18, 0.34, 1.00), (0.00, 0.00, 0.39)\rangle$	0.24	0.46	0.228	3

The overall performance ranking results are shown in Table 12.

The ranking results obtained by using Procedures I, II and III are shown in Tables 13, 14 and 15.

Results of ranking alternatives on the basis of ranking procedures discussed in Section 2 are shown in Table 16.

Table 15
The ranking results obtained on the basic Procedure III.

A^* alternatives	$\langle(0.75, 1.00, 1.00), (0.00, 0.00, 0.18)\rangle$	d_i	Rank
A_1	$\langle(0.75, 1.00, 1.00), (0.00, 0.00, 0.18)\rangle$	0.00	1
A_2	$\langle(0.69, 1.00, 1.00), (0.00, 0.00, 0.18)\rangle$	0.01	2
A_3	$\langle(0.18, 0.34, 1.00), (0.00, 0.00, 0.39)\rangle$	0.24	3

Table 16
The summarized ranking results.

Alternatives	Procedure I		Procedure II		Procedure III	
	S_i	Rank	S_i	Rank	S_i	Rank
A_1	0.856	1	0.766	1	0.00	1
A_2	0.835	2	0.764	2	0.01	2
A_3	0.376	3	0.228	3	0.24	3

The results obtained in the above considered case study indicate that all of three procedures discussed in Section 2 provide the same ranking order of the considered alternatives.

In order to further prove the applicability of the proposed procedure for ranking TIFNs based on the use of Hamming distance, a comparison of ranking procedure based on Score and Accuracy and Ranking procedure based on Hamming distance has been shown in Appendix A.

6. Conclusion

Many real-world decision-making problems are complex and related to ambiguities, uncertainties and vagueness.

The fuzzy set theory provides an efficient way for dealing with ambiguities, uncertainties and vagueness. Intuitionistic fuzzy numbers, due to their functions of belonging and not belonging to a set, indicate the possibility of using a smaller number of, usually more complex, criteria. In other words, in the case of using intuitionistic fuzzy numbers, respondents have an opportunity to state their satisfaction and dissatisfaction levels, which allows the use of the MCDM model with a smaller number of the evaluation criteria. However, the use of intuitionistic fuzzy numbers can be quite complex for respondents.

To demonstrate the usability of TIFNs for solving complex MCDM problems in this manuscript a framework is proposed. The proposed framework is based on the use of a smaller number of evaluation criteria whose performance ratings are evaluated using linguistic variables whose meaning is mapped into appropriate TIFNs. In order to get as close as possible to the real respondents' attitudes, in this framework is also considered a guided survey, which should facilitate the use of TIFNs.

Finally, the applicability and the effectiveness of the proposed framework is considered and demonstrated with the case study of the evaluation of the hotels' websites.

The obtained results indicate the applicability of the proposed approach. Therefore, it is also planned to consider its applicability for evaluating different types of e-commerce websites.

In the proposed approach, the applicability of three procedures for ranking TIFNs was considered, of which one is newly proposed. The newly proposed procedure, based on the use of Hamming distance, provides results similar to the remaining procedures. For this reason, its further verification is also planned, as well as its use for solving similar problems.

Appendix A: Comparison of Procedures for Ranking IFNs Based on the Score Function and Hamming Distance

This appendix shows one analysis of ranking TIFNs based on the use of the procedure proposed by Xu and Yager (2006) and the procedure based on the use of Hamming distance. This analysis starts with the TIFN $\tilde{A}_1 = \langle(0.4, 0.5, 0.6), (0.4, 0.5, 0.6)\rangle$, which is slightly modified by changing its left borders l and l'. The TIFN $\tilde{A}_1$ and its variations are shown in Table A.1 and in Figs. A.1, A.2 and A.3.

The ranking results for TIFNs from Table A.1 obtained by using the procedure proposed by Xu and Yager (2006), i.e. the procedure based on the use of Score and Accuracy functions, are shown in Table A.2.

The ranking results obtained by using the procedure based on the use of Hamming distance are shown in Table A.3.

Table A.1
TIFN $\tilde{A}_1$ and some its variations.

TIFNs	The membership and the non-membership of TIFNs
$\tilde{A}_1$	$\langle(0.4, 0.5, 0.6), (0.4, 0.5, 0.6)\rangle$
$\tilde{A}_{21}$	$\langle(0.4, 0.5, 0.6), (0.3, 0.5, 0.6)\rangle$
$\tilde{A}_{22}$	$\langle(0.3, 0.5, 0.6), (0.3, 0.5, 0.6)\rangle$
$\tilde{A}_{31}$	$\langle(0.5, 0.5, 0.6), (0.5, 0.5, 0.6)\rangle$
$\tilde{A}_{32}$	$\langle(0.5, 0.5, 0.6), (0.4, 0.5, 0.6)\rangle$

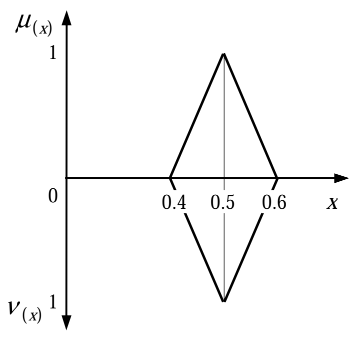

Fig. A.1. The TIFN $\tilde{A}_1$.

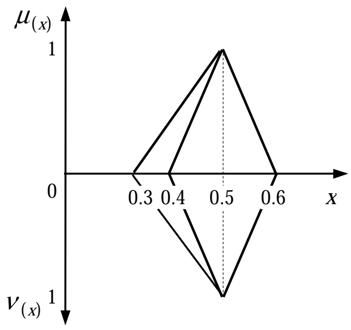

Fig. A.2. The variations of TIFN $\tilde{A}_1$: $\tilde{A}_{21}$ and $\tilde{A}_{22}$.

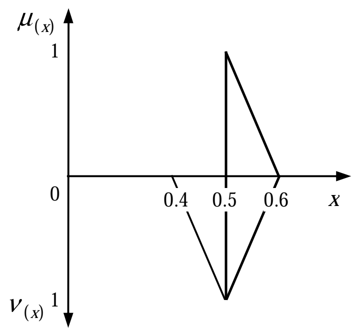

Fig. A.3. The variations of TIFN $\tilde{A}_1$: $\tilde{A}_{31}$ and $\tilde{A}_{32}$.

Table A.2
Ranking results obtained by using Score and Accuracy functions.

Alternatives	TIFNs	Score		Accuracy		Final ranking order
		S_A	Rank	H_A	Rank	
$\tilde{A}_1$	$\langle(0.4, 0.5, 0.6), (0.4, 0.5, 0.6)\rangle$	0.00	2	1.00	1	2
$\tilde{A}_{21}$	$\langle(0.4, 0.5, 0.6), (0.3, 0.5, 0.6)\rangle$	0.03	1	0.97		1
$\tilde{A}_{22}$	$\langle(0.3, 0.5, 0.6), (0.3, 0.5, 0.6)\rangle$	0.00	2	0.93	2	3
$\tilde{A}_{31}$	$\langle(0.5, 0.5, 0.6), (0.5, 0.5, 0.6)\rangle$	−1.50	5	2.57		5
$\tilde{A}_{32}$	$\langle(0.5, 0.5, 0.6), (0.4, 0.5, 0.6)\rangle$	−1.17	4	2.23		4

Table A.3
Ranking results obtained by using Hamming distance.

Alternatives	TIFNs	Hamming	
		H_A	Rank
$\tilde{A}_1$	$\langle(0.4, 0.5, 0.6), (0.4, 0.5, 0.6)\rangle$	0.010	2
$\tilde{A}_{21}$	$\langle(0.4, 0.5, 0.6), (0.3, 0.5, 0.6)\rangle$	0.000	1
$\tilde{A}_{22}$	$\langle(0.3, 0.5, 0.6), (0.3, 0.5, 0.6)\rangle$	0.010	2
$\tilde{A}_{31}$	$\langle(0.5, 0.5, 0.6), (0.5, 0.5, 0.6)\rangle$	0.480	5
$\tilde{A}_{32}$	$\langle(0.5, 0.5, 0.6), (0.4, 0.5, 0.6)\rangle$	0.380	4

Table A.4
Ranking results obtained by using Score and Accuracy functions.

Alternatives	TIFNs	Score		Accuracy		Final ranking order
		S_A	Rank	H_A	Rank	
$\tilde{A}_1$	$\langle(0.4, 0.5, 0.6), (0.4, 0.5, 0.6)\rangle$	0.00	1	1.00	1	1
$\tilde{A}_2$	$\langle(0.3, 0.5, 0.6), (0.4, 0.5, 0.6)\rangle$	−0.03	3	0.97		3
$\tilde{A}_3$	$\langle(0.3, 0.5, 0.6), (0.3, 0.5, 0.6)\rangle$	0.00	1	0.93	2	2

The ranking results presented in Tables A.2 and A.3 indicate a high similarity between the ranking orders obtained by the use of the Score function and the Hamming distance. However, it should also be noted that these results are not always the same.

Table A.4 shows the ranking results of the three TIFNs obtained on the basis of the Score and Accuracy functions, as well as the Hamming distance.

The results presented in Tables A.4 indicate a high similarity between the ranking results obtained after the application of the Score function and the Hamming distance.

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