Fuzzy linguistic ranking model for Web Accessibility Test tools

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***Abstract*—There are dozens of tools to automatically evaluate web accessibility. Some are online, and some are toolbars to complement web browsers. In order to select the best Web Accessibility Test Tool, various aspects should be considered. Among the various aspects, the evaluation environment has an important role to assume in the evaluation criteria of the website. The ability to evaluate websites that require user permissions or they are freely accessible could affect the accessibility outcome due to limited or no access to the tool. In addition, the interpretability of the results differs from one tool to another, and it can be difficult to identify the areas of opportunity for improvement of the website evaluated. To select the best tool that matches experts' needs, it is important to have a group of experts in the area. These experts will give their opinions on the criteria according to which the tools will be evaluated. Each Web Accessibility Test Tool is an alternative in a decision making problem (DM). A DM which is evaluated by a group of experts is called a Multi-Expert Multi-Criteria (MEMC). Contrary to studies where the assessments are quantitative, this research uses Computing with Words (CW) processes. Because experts may have uncertainty at the time of issuing their evaluation, Intuitionistic Fuzzy Sets (IFS) are used to work with that uncertainty. Finally, a ranking of the evaluated tools is carried out by TOPSIS.**

***Keywords*—Intuitionistic Fuzzy Set (IFS), TOPSIS, Multi-Expert Multi-Criteria Linguistic Decision Making (MEMCLDM), Web Accesibility Tools Test, Ranking.**

I. Introduction

The World Wide Web Consortium (W3C) is an international community working towards international standards for the web. W3C dictates a series of standards –WCAG 1.0 [1] in 1999 and WCAG 2.0 [2] in 2008– to make web information accessible to everyone regardless of hardware, software, network infrastructure, language, culture, geographic location, or physical or mental ability. Currently there are several tools that evaluate the accessibility of websites automatically. The tools contain different features that may or may not facilitate the evaluation of the site depending on the context in which are applied. Choosing the right tool for the expert's needs is a decision making problem (DM). A DM is a typical problem that has different alternatives to choose from valued by experts in the topic.

In this document, a fuzzy linguistic model is proposed for evaluating accessibility tools through nine criteria: (1) Learnability, (2) Scope of application, (3) Displays element evaluation,ig (4) Accessibility level, (5) Accuracy, (6) CSS evaluation, (7) Reports, (8) Intuitivity, (9) Standardized output. Commonly, the valuation process is done using numerical scales. This research makes use of enhanced linguistic terms in order to take advantage of the knowledge and experience of the experts in a better way, since the evaluation is performed using natural language. The decision-making process is carried out by intuitionist linguistic representation using linguistic sets in the expert opinions on the criteria to be evaluated of the accessibility tools. Finally, using TOPSIS, the results are aggregated to rank the tools evaluated.

This document is structured as follows: Section II provides a descriptive summary of the preliminaries relating to the Intuitionist linguistic model as well as TOPSIS as a technique for the ranking of alternatives. In Section III, we present a Fuzzy linguistic ranking model. In Section IV, we apply a ranking model for Web Accessibility Test tools. Finally, in Section V, the conclusions are presented.

[1]https://www.w3.org/TR/WAI-WEBCONTENT/
[2]https://www.w3.org/TR/WCAG20/

II. Preliminaries

This section describes the methodologies applied to the Multi-Expert Multi-Criteria Linguistic Decision Making (MEMCLDM) problem for ranking in the alternative selection.

A. Multi Criteria Decision Making

The Multi-Criteria Decision Making (MCDM) was introduced in the early 1970s. It is a tool used for problem assessment and decision making with multiple alternatives that are evaluated considering multiple criteria [1], [2].

MCDM often deal with different types of problems such as selection, ranking and classification problems. The aim on each kind of problem is different: (1) selection problems is expected to find the best alternative; (2) the ranking problems are aimed at determining the suitability of all alternatives, which is presented as a hierarchy from the best to the worst and (3) in the classification problems we want to know which alternatives belong to which class of a predefined set of ordered classes.

There are several methods of solving MCDM problems that are used to form a ranking of alternatives. The TOPSIS method [3] is one of them. TOPSIS is based on an aggregation function of the experts' evaluation scores and determines the best alternative by calculating the distances between the positive and negative ideal solution.

MCDM problems can be evaluated by various experts to be approached as MEMCLDM problems. These experts are usually people with experience in the subject to be assessed. Alternatives can be assessed quantitatively or qualitatively. To evaluate qualitative information, the use of the Fuzzy Set Theory (FST) [4], proposed by Zadeh in 1965, has been very successful. In order to achieve an efficient evaluation of the perception of the experts, the use of linguistic variables[5] and the procedures of Computation with Words (CW) [6], [7] are used in intelligent computer systems [8], [9], [10], [11].

B. Intuitionistic fuzzy representation model

Intuitionistic Fuzzy Set (IFS) was proposed by Atanassov in 1986. IFS [12] is characterized by having simultaneously a membership and a non-membership with a degree of hesitance. The IFS are models of information representation used to support decision making and are very useful because of the ability to express imprecise or uncertain information more flexibly than the traditional fuzzy sets [2], [13].

According to Atanassov [12] an IFS A, in the universe $X = \{x_1, x_2, \ldots, x_n\}$, it is represented as:

$$\widetilde{A} = \langle x_j, \mu_{\widetilde{A}}(x_j), \nu_{\widetilde{A}}(x_j)\rangle \mid x_j \in X$$

where $\mu_{\widetilde{A}}(x_j) \in [0,1]$ and $\nu_{\widetilde{A}}(x_j) \in [0,1]$ represents respectively the membership and the non-membership degrees of the element x_j. Then an IFS has the following requirement:

$$0 \leq \mu_{\widetilde{A}}(x_j) + \nu_{\widetilde{A}}(x_j) \leq 1$$

The function $\pi_{\widetilde{A}}(x_j)$ represents the degree of hesitancy of x_j and it is defined as:

$$\pi_{\widetilde{A}}(x_j) = 1 - \mu_{\widetilde{A}}(x_j) - \nu_{\widetilde{A}}(x_j)$$

Let α and β be two intuitionistic fuzzy sets, λ be a number. Hence, the main algebraic operations of any two intuitionistic fuzzy sets $\alpha = (\mu_\alpha, \nu_\alpha)$ and $\beta = (\mu_\beta, \nu_\beta)$ can be defined in the following way [14] and [15]:

1) *Addition* $\oplus$*:*

$$\alpha \oplus \beta = (\mu_\alpha + \mu_\beta - \mu_\alpha\mu_\beta, \nu_\alpha\nu_\beta); \tag{1}$$

2) *Product* $\otimes$*:*

$$\alpha \otimes \beta = (\mu_\alpha\mu_\beta, \nu_\alpha + \nu_\beta - \nu_\alpha\nu_\beta); \tag{2}$$

3) *Scalar product:*

$$\lambda\alpha = (1 - (1 - \mu_\alpha)^\lambda, \nu_\alpha^\lambda), \lambda > 0; \tag{3}$$

4) *Scalar power:*

$$\alpha^\lambda = (\mu_{\alpha^\lambda}, 1 - (1 - \nu_\alpha)^\lambda), \lambda > 0. \tag{4}$$

The Intuitionistic Fuzzy Weighted Average (IFWA) aggregation operator was initially proposed by [15], it has been used to aggregate the individual opinions of decision makers [16], [17]. Let $R^{(k)} = (r_{ij}^{(k)})m \times n$ be an intuitionist decision-making matrix with the evaluations of each alternative A_i with $(i = 1, \ldots, m)$ and criterion C_j with $(j = 1, \ldots, n)$ by each decision maker DM_k with $(k = 1, \ldots, d)$. Let w_k be the weight of each decision maker DM_k where $\Sigma_{k=1}^{n} w_k = 1$. Then the final result of applying the $IFWA_w$ aggregation operatio operator is an IFS value given by Eq.(5):

$$\begin{aligned} IFWA_w &= IFWA_w(r_{ij}^{(1)}, r_{ij}^{(2)}, \ldots, r_{ij}^{(d)}) \\ &= w_1 r_{ij}^{(1)} \oplus w_2 r_{ij}^{(2)} \oplus w_3 r_{ij}^{(3)} \oplus \cdots \oplus w_k r_{ij}^{(d)} \\ &= [\chi, \psi, \delta] \end{aligned} \tag{5}$$

where

$$\begin{aligned} \chi &= 1 - \Pi_{k=1}^{d}(1 - \mu_{ij}^{(k)})^{w_k} \\ \psi &= \Pi_{k=1}^{d}(\nu_{ij}^{(k)})^{w_k} \\ \delta &= \Pi_{k=1}^{d}(1 - \mu_{ij}^{(k)})^{w_k} - \Pi_{k=1}^{d}(\nu_{ij}^{(k)})^{w_k}. \end{aligned}$$

Intuitionistic fuzzy representation has been widely used with multicriteria decision-making techniques [18] such as Intuitionistic fuzzy TOPSIS [17], Intuitionistic fuzzy AHP [19], Intuitionistic fuzzy VIKOR [20], Intuitionistic fuzzy ELECTRE [21], among others, with the purpose of order the alternatives.

C. Intuitionistic fuzzy TOPSIS

There are different techniques for the ranking of alternatives in MEMCLDM. TOPSIS is a technique which uses the order by similarity with an ideal solution [3]. TOPSIS is based on the fact that the alternative selected must be the one that contains the closest distance from the ideal solution and the furthest distance from the negative solution. The Fuzzy TOPSIS technique is widely applied in decision making [22] and it is considered as one of the best MCDM methods to solve problems. Due to its simplicity of application avoiding it application in alternatives ranking when a new alternative is inserted [23]. Boran et al. [16] proposes the Intuitionistic fuzzy TOPSIS to be applied following these steps:

1) Let $W_j = (\mu_j, \nu_j)$ be the intuitionistic fuzzy weight of each criteria C_j according to alternative A_i. Let $R' = (r'_{ij})_{m\times n}$ be the matrix of the aggregated intuitionistic fuzz sets with m alternatives and n criteria. Then the weighted normalized matrix is calculated by Eq.(6) and Eq.(7).

$$R' \otimes W_i = \{(\mu_{r'_{ij}}\mu_{W_j}, \nu_{r'_{ij}} + \nu_{W_j} - \nu_{r'_{ij}}\nu_{W_j}) \mid r'_{ij} \in R'\} \tag{6}$$

$$\pi_{r'_{ij}} = (1 - \nu_{r'_{ij}} - \nu_{W_j} - \mu_{r'_{ij}}\mu_{W_j} + \nu_{r'_{ij}}\nu_{W_j}) \tag{7}$$

2) The positive intuitionistic fuzzy ideal solution vector A^+ can be determined as:

$$A^+ = (\mu_{A^-}W_j, \nu_{A^+}W_j) \tag{8}$$

where

$$\mu_{A^+}W_j = \max_i \mu_{r'_{ij}} W_j$$
$$\nu_{A^+}W_j = \min_i \nu_{r'_{ij}} W_j.$$

3) The negative intuitionistic fuzzy ideal solution vector A^- can be determined as:

$$A^- = (\mu_{A^-}W_j, \nu_{A^-}W_j) \quad (9)$$

where

$$\mu_{A^-}W_j = min_i \mu_{r'_{ij}W_j}$$
$$\nu_{A^-}W_j = max_i \nu_{r'_{ij}W_j}.$$

4) Calculate the distance measurement, using the Euclidean distance. The separation of each alternative from the ideal solution is given as:

$$S_i^+ = \sqrt{\tfrac{1}{2n}\Sigma_{j=1}^n[(\mu_{r'_{ij}} W_j - \mu_{A^+}W_j)^2 + (\nu_{r'_{ij}} W_j - \nu_{A^+}W_j)^2 + (\pi_{r'_{ij}} W_j - \pi_{A^+}W_j)^2]}. \quad (10)$$

5) Similarly, the separation of the negative solution is given as:

$$S_i^- = \sqrt{\tfrac{1}{2n}\Sigma_{j=1}^n[(\mu_{r'_{ij}} W_j - \mu_{A^-}W_j)^2 + (\nu_{r'_{ij}} W_j - \nu_{A^-}W_j)^2 + (\pi_{r'_{ij}} W_j - \pi_{A^-}W_j)^2]}. \quad (11)$$

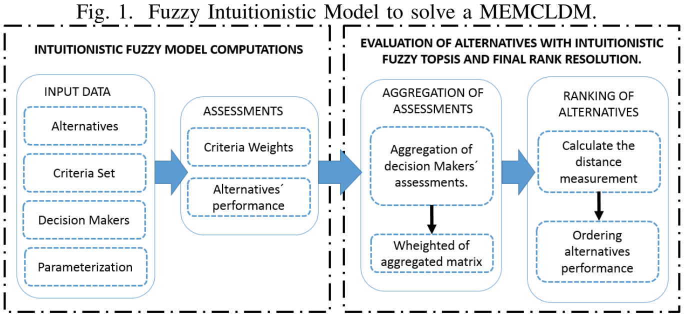
6) Then rank the order of preference by the relative proximity coefficient as:

$$RP_{A_i} = \frac{S_i^-}{S_i^- + S_i^+}. \quad (12)$$

III. A Fuzzy linguistic ranking model

The proposed model for the ranking problem of the list of tools for evaluating Web Accessibility Test tools consists of three basic stages: (1) Representation phase, (2) Aggregation phase and (3) Exploitation phase. Figure (1) presents the proposed phases:

Fig. 1. Fuzzy Intuitionistic Model to solve a MEMCLDM.



A. Representation phase

The first phase consist of the definition of Linguistic Terms Set (LTS) that will be used for decision making. Decision makers denoted as DM_k with $(k = 1, \ldots, d)$. Should be select a set of diverse DM that have experience and knowledge directly related to the problem to evaluate the available alternatives. The set of alternatives A_i with $(i = 1, \ldots, m)$ are evaluated using a set of criteria C_j with $(j = 1, \ldots, n)$. The weight W_j of each criterion C_j assigned by a coordinator using an Intuitionistic Fuzzy Linguistic Set (IFLS). It would be desirable to represent the input linguistic information with a representation able to express uncertainty and subjectivity in judgments.

B. Aggregation phase

The second phase consists of aggregating the decision makers judgments. The IFWA operator presented in Eq. (5) can be used to aggregate them into a matrix of group decision making $R' = (r'_{ij})_{m\times n}$, where m and n denotes the number of evaluated alternatives and criteria respectively. Next, a weighting process of the group decision making matrix R' is performed using the weight vector W_j and applying Eq. (6) and Eq. (7).

C. Exploitation phase

In the last step of the decision-making process, the performance of each alternative should be calculated using the distance measurement. The ideal intuitionistic fuzzy positive and negative solutions are obtained as Eq. (8) and Eq. (9). The distance between each aggregated weighted evaluation of alternatives' performances and the ideal intuitionistic fuzzy positive and negative solution is calculated by Eq. (10) and Eq. (11). The final score of the alternatives performance is calculated by relative proximity as in Eq. (12). Finally, the alternatives are ordered.

IV. A ranking model for Web Accessibility Test tools

It is desired to evaluate the level of accessibility of a web system. There are several tools supported by the World Wide Web Consortium (W3C) with different features. The DM set limits the main set to the six tools commonly used among them. The set of Web Accessibility Test (WAT) tools are evaluated in relation to a set of nine criteria. It must be decided which of this set of six tools is best suited to your needs. The tools considered are the following:

1) Wave[3] (c_1),
2) Achecher[4] (c_2),
3) eXaminator[5] (c_3),
4) AccessMonitor[6] (c_4),
5) Accessibility Check[7] (c_5),
6) TAW[8] (c_6).

A. Representation phase

For this case-study there are $d = 7$ decision makers who have knowledge in web development. The set of $m = 6$ WAT tools are assessed according to a set of $n = 9$ criteria described in Table (I). The linguistic intuitionistic variables in

[3]http://wave.webaim.org/
[4]https://achecker.ca/checker/index.php
[5]http://examinator.ws/
[6]http://www.acessibilidade.gov.pt/accessmonitor/
[7]http://www.etre.com/tools/accessibilitycheck/
[8]https://www.tawdis.net/

TABLE I
DESCRIPTION OF THE CRITERIA USED TO EVALUATE WEB ACCESSIBILITY TOOLS.

Criteria for evaluating accessibility assessment tools.		
Criteria C_j		Definition
c_1	Learnability	Enables simple and efficient learning.
c_2	Scope of application	Allows evaluation on sites with user permissions from an external site.
c_3	Displays element evaluation	Reveals the evaluations of each element to resolve any errors efficiently.
c_4	Accessibility level	Calculates the overall level of accessibility (A, AA, AAA).
c_5	Accuracy	Describes the assessments: (1) failed, 2 (warning) and (3) passed in a similar form as a manual assessment.
c_6	CSS evaluation	Evaluates accessibility of CSS content.
c_7	Reports	Generates reports that are easily interpreted by experts as ordinary users.
c_8	Intuitivity	Indicates inspected items for easy identification of errors, warnings and approvals.
c_9	Standardized output	Provides a report in standardized format: XML, JSON and YAML.

TABLE II
LINGUISTIC VARIABLES FOR THE IMPORTANCE WEIGHT OF EACH CRITERIA EXPRESSED AS IFS

Label	Short	μ	ν
Very High	VH	0.90	0.05
High	H	0.75	0.20
Medium	M	0.50	0.45
Low	L	0.35	0.60
Very Low	VL	0.10	0.90

Table (II) were used by a coordinator to define the weight W_j of each criteria C_j, as presented in Table (III). Also, using Table (II), each DM_k evaluates the performance of each alternative in each criterion. Table (IV) presents decision makers assessments.

B. Aggregation phase

Once the individual matrix of intuitionistic evaluations has been obtained, the matrix must be aggregated using the IFWA operator presented in Eq. (5). In this study-case, the weight of the decision makers were considered the same. The IFWA operator is used to aggregate them into a group decision making matrix. The aggregation results are presented in Table (V). Due to the space, only two assessments are displayed. Next, a weighting process of the group decision matrix R' is performed using the weight vector W_j and applying the Eq. (6) and Eq. (7). The results of the weighted aggregation for the criteria c_1 and c_2 are displayed in Table (VI).

TABLE III
INTUITIONISTIC FUZZY NUMBER (IFN) FOR EACH LINGUISTIC LABEL IN EACH CRITERIA

Intuitionistic Fuzzy Sets				
C_j	Criteria	Assessment	μ	ν
c_1	Learnability	Very High	0.90	0.05
c_2	Scope of application	Very High	0.90	0.05
c_3	Displays element evaluation	High	0.75	0.20
c_4	Accessibility level	Medium	0.50	0.45
c_5	Accurancy	High	0.75	0.20
c_6	Css evaluation	Medium	0.50	0.45
c_7	Reports	High	0.75	0.20
c_8	Intuition	High	0.75	0.20
c_9	Standardized output	Very High	0.90	0.05

C. Exploitation phase

In this step, the performance of each alternative should be calculated using the distance measurement from Fuzzy TOPSIS technique. The intuitionistic fuzzy ideal positive and negative solution are founded using Eq. (8) and Eq. (9). The distance between each aggregate weighted evaluation of the alternatives' results and the intuitionistic fuzzy ideal positive and negative solution is calculated using the Eq. (10) and Eq. (11). The results are presented by Table (VIII) and Table (IX) respectively.

Finally, the alternatives are ordered by relative proximity as in Eq. (12). The resulting order is presented in Table (X) with $a_1 > a_2 > a_6 > a_5 > a_3 > a_4$. Alternative a_1 is selected as the best tool with the best scores in 6 of 9 criteria evaluated. The selected tool can be highlight as very intuitive, since it marks errors and warnings in the html label, due this, it is easy to identify where are the errors.

V. CONCLUSION

This study proposed and tested a Multi-Expert Multi-Criteria Decision model in order to evaluate and select Web Accessibility Test tools that combines the Intuitionistic fuzzy representation and the TOPSIS technique. It fulfills several important characteristics for a decision making process:

- The use of linguistic variables instead of numerical scales enhances the assessment of alternatives in decision-making problems because the cognitive processes of human beings accept words rather than numbers;
- The use of Intuitionistic Fuzzy Set (ISF) is used due to the imprecision found in the parameterization since there may be a degree of hesitation. IFS takes into account the degree of membership, degree of non-membership and hesitancy;
- Finally, being able to rank the alternatives with fuzzy information allows a better interpretability of results for decision makers.

The Wave tool resulted best valuated in comparison with five tools. Wave is considered an easy learning tool, the plug-in installation to the browser is very simple. Wave has a high degree of intuitiveness and as a toolbar, it allows the evaluation of websites with the users' permissions. The assessment is displayed on each element evaluated, enabling rapid identification of errors and warnings. Experts rank the Wave tool first, considering the set of criteria. As a further research, it is suggested to explore other techniques in combination with linguistic fuzzy representations and compare their results with the proposal presented in this study.

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REFERENCES

[1] S. Pohekar and M. Ramachandran, "Application of multi-criteria decision making to sustainable energy planning—a review," *Renewable and Sustainable Energy Reviews*, vol. 8, no. 4, pp. 365–381, 2004.

TABLE IV
Valuations of $d = 7$ Decision makers for $m = 6$ alternatives according to $n = 9$ criteria

Criteria	Alternatives	dm_1			dm_2			dm_3		
		Linguistic label	μ	ν	Linguistic label	μ	ν	Linguistic label	μ	ν
c_1	a_1	VH	0.90	0.05	VH	0.90	0.05	H	0.75	0.20
	a_2	VH	0.90	0.05	VH	0.90	0.05	H	0.75	0.20
	a_3	VH	0.90	0.05	VH	0.90	0.05	H	0.75	0.20
	a_4	M	0.50	0.45	VH	0.90	0.05	VH	0.90	0.05
	a_5	L	0.35	0.60	M	0.50	0.45	VH	0.90	0.05
	a_6	VH	0.90	0.05	H	0.75	0.20	H	0.75	0.20
c_2	a_1	VH	0.90	0.05	VH	0.90	0.05	M	0.50	0.45
	a_2	H	0.75	0.20	VL	0.10	0.90	H	0.75	0.20
	a_3	H	0.75	0.20	VH	0.90	0.05	M	0.50	0.45
	a_4	H	0.75	0.20	L	0.35	0.60	H	0.75	0.20
	a_5	M	0.50	0.45	H	0.75	0.20	H	0.75	0.20
	a_6	VH	0.90	0.05	H	0.75	0.20	H	0.75	0.20
c_3	a_1	H	0.75	0.20	VH	0.90	0.05	M	0.50	0.45
	a_2	VH	0.90	0.05	M	0.50	0.45	M	0.50	0.45
	a_3	H	0.75	0.20	VL	0.10	0.90	M	0.50	0.45
	a_4	L	0.35	0.60	VL	0.10	0.90	H	0.75	0.20
	a_5	M	0.50	0.45	VL	0.10	0.90	H	0.75	0.20
	a_6	M	0.50	0.45	H	0.75	0.20	M	0.50	0.45
c_4	a_1	H	0.75	0.20	VL	0.10	0.90	VH	0.90	0.05
	a_2	H	0.75	0.20	H	0.75	0.20	VL	0.10	0.90
	a_3	H	0.75	0.20	H	0.75	0.20	VL	0.10	0.90
	a_4	L	0.35	0.60	VL	0.10	0.90	VL	0.10	0.90
	a_5	VL	0.10	0.90	VH	0.90	0.05	VL	0.10	0.90
	a_6	VH	0.90	0.05	H	0.75	0.20	VL	0.10	0.90
c_5	a_1	H	0.75	0.20	VH	0.90	0.05	M	0.50	0.45
	a_2	H	0.75	0.20	VH	0.90	0.05	H	0.75	0.20
	a_3	H	0.75	0.20	VL	0.10	0.90	H	0.75	0.20
	a_4	L	0.35	0.60	L	0.35	0.60	H	0.75	0.20
	a_5	M	0.50	0.45	L	0.35	0.60	H	0.75	0.20
	a_6	VH	0.90	0.05	H	0.75	0.20	M	0.50	0.45
c_6	a_1	H	0.75	0.20	VL	0.10	0.90	M	0.50	0.45
	a_2	H	0.75	0.20	M	0.50	0.45	VL	0.10	0.90
	a_3	H	0.75	0.20	L	0.35	0.60	VL	0.10	0.90
	a_4	VL	0.10	0.90	VL	0.10	0.90	M	0.50	0.45
	a_5	M	0.50	0.45	H	0.75	0.20	M	0.50	0.45
	a_6	VH	0.90	0.05	M	0.50	0.45	VL	0.10	0.90
c_7	a_1	H	0.75	0.20	M	0.50	0.45	M	0.50	0.45
	a_2	VH	0.90	0.05	M	0.50	0.45	M	0.50	0.45
	a_3	L	0.35	0.60	VH	0.90	0.05	M	0.50	0.45
	a_4	VL	0.10	0.90	VL	0.10	0.90	M	0.50	0.45
	a_5	L	0.35	0.60	L	0.35	0.60	M	0.50	0.45
	a_6	H	0.75	0.20	M	0.50	0.45	M	0.50	0.45
c_8	a_1	VH	0.90	0.05	VH	0.90	0.05	H	0.75	0.20
	a_2	H	0.75	0.20	M	0.50	0.45	H	0.75	0.20
	a_3	H	0.75	0.20	VL	0.10	0.90	M	0.50	0.45
	a_4	L	0.35	0.60	L	0.35	0.60	M	0.50	0.45
	a_5	L	0.35	0.60	L	0.35	0.60	M	0.50	0.45
	a_6	H	0.75	0.20	H	0.75	0.20	M	0.50	0.45
c_9	a_1	H	0.75	0.20	VL	0.10	0.90	VH	0.90	0.05
	a_2	H	0.75	0.20	VH	0.90	0.05	L	0.35	0.60
	a_3	M	0.50	0.45	VL	0.10	0.90	L	0.35	0.60
	a_4	L	0.35	0.60	VL	0.10	0.90	L	0.35	0.60
	a_5	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60
	a_6	VL	0.10	0.90	M	0.50	0.45	M	0.50	0.45

Criteria	Alternatives	dm_4			dm_5			dm_6			dm_7		
		Linguistic label	μ	ν	Linguistic label	μ	ν	Linguistic label	μ	ν	Linguistic label	μ	ν
c_1	a_1	VH	0.90	0.05	VH	0.90	0.05	H	0.75	0.20	H	0.75	0.20
	a_2	H	0.75	0.20	VH	0.90	0.05	L	0.35	0.60	H	0.75	0.20
	a_3	H	0.75	0.20	VH	0.90	0.05	H	0.75	0.20	M	0.50	0.45
	a_4	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60
	a_5	VH	0.90	0.05	H	0.75	0.20	M	0.50	0.45	L	0.35	0.60
	a_6	VH	0.90	0.05	H	0.75	0.20	M	0.50	0.45	H	0.75	0.20
c_2	a_1	VH	0.90	0.05	VH	0.90	0.05	H	0.75	0.20	VH	0.90	0.05
	a_2	M	0.50	0.45	M	0.50	0.45	M	0.50	0.45	VL	0.10	0.90
	a_3	M	0.50	0.45	H	0.75	0.20	VL	0.10	0.90	H	0.75	0.20
	a_4	M	0.50	0.45	H	0.75	0.20	H	0.75	0.20	VL	0.10	0.90
	a_5	M	0.50	0.45	M	0.50	0.45	H	0.75	0.20	M	0.50	0.45
	a_6	VH	0.90	0.05	H	0.75	0.20	H	0.75	0.20	H	0.75	0.20
c_3	a_1	VH	0.90	0.05	VH	0.90	0.05	H	0.75	0.20	VH	0.90	0.05
	a_2	VH	0.90	0.05	VH	0.90	0.05	M	0.50	0.45	H	0.75	0.20
	a_3	H	0.75	0.20	M	0.50	0.45	M	0.50	0.45	H	0.75	0.20
	a_4	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60	VL	0.10	0.90
	a_5	VH	0.90	0.05	H	0.75	0.20	VL	0.10	0.90	M	0.50	0.45
	a_6	M	0.50	0.45	M	0.50	0.45	M	0.50	0.45	H	0.75	0.20
c_4	a_1	H	0.75	0.20	H	0.75	0.20	L	0.35	0.60	M	0.50	0.45
	a_2	VH	0.90	0.05	H	0.75	0.20	VH	0.90	0.05	VL	0.10	0.90
	a_3	VH	0.90	0.05	H	0.75	0.20	M	0.50	0.45	H	0.75	0.20
	a_4	VL	0.10	0.90	VL	0.10	0.90	VL	0.10	0.90	VL	0.10	0.90
	a_5	VH	0.90	0.05	VH	0.90	0.05	VH	0.90	0.05	VL	0.10	0.90
	a_6	VH	0.90	0.05	VH	0.90	0.05	VH	0.90	0.05	H	0.75	0.20
c_5	a_1	H	0.75	0.20	VH	0.90	0.05	H	0.75	0.20	H	0.75	0.20
	a_2	H	0.75	0.20	H	0.75	0.20	H	0.75	0.20	M	0.50	0.45
	a_3	H	0.75	0.20	H	0.75	0.20	L	0.35	0.60	M	0.50	0.45
	a_4	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60
	a_5	VH	0.90	0.05	H	0.75	0.20	L	0.35	0.60	M	0.50	0.45
	a_6	VH	0.90	0.05	H	0.75	0.20	M	0.50	0.45	H	0.75	0.20
c_6	a_1	VH	0.90	0.05	VH	0.90	0.05	VL	0.10	0.90	H	0.75	0.20
	a_2	VH	0.90	0.05	H	0.75	0.20	H	0.75	0.20	L	0.35	0.60
	a_3	VH	0.90	0.05	M	0.50	0.45	H	0.75	0.20	M	0.50	0.45
	a_4	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60
	a_5	H	0.75	0.20	H	0.75	0.20	H	0.75	0.20	M	0.50	0.45
	a_6	VH	0.90	0.05	M	0.50	0.45	H	0.75	0.20	M	0.50	0.45
c_7	a_1	H	0.75	0.20	M	0.50	0.45	H	0.75	0.20	M	0.50	0.45
	a_2	H	0.75	0.20	M	0.50	0.45	M	0.50	0.45	M	0.50	0.45
	a_3	H	0.75	0.20	VH	0.90	0.05	L	0.35	0.60	VL	0.10	0.90
	a_4	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60	M	0.50	0.45
	a_5	VH	0.90	0.05	H	0.75	0.20	L	0.35	0.60	L	0.35	0.60
	a_6	H	0.75	0.20	VH	0.90	0.05	H	0.75	0.20	M	0.50	0.45
c_8	a_1	H	0.75	0.20	H	0.75	0.20	H	0.75	0.20	H	0.75	0.20
	a_2	H	0.75	0.20	H	0.75	0.20	M	0.50	0.45	M	0.50	0.45
	a_3	H	0.75	0.20	VH	0.90	0.05	L	0.35	0.60	M	0.50	0.45
	a_4	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60
	a_5	VH	0.90	0.05	VH	0.90	0.05	L	0.35	0.60	M	0.50	0.45
	a_6	H	0.75	0.20	VH	0.90	0.05	M	0.50	0.45	H	0.75	0.20
c_9	a_1	VL	0.10	0.90	VL	0.10	0.90	H	0.75	0.20	VL	0.10	0.90
	a_2	VH	0.90	0.05	H	0.75	0.20	M	0.50	0.45	VL	0.10	0.90
	a_3	VL	0.10	0.90	VL	0.10	0.90	L	0.35	0.60	VL	0.10	0.90
	a_4	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60	L	0.35	0.60
	a_5	VL	0.10	0.90	M	0.50	0.45	L	0.35	0.60	VL	0.10	0.90
	a_6	L	0.35	0.60	M	0.50	0.45	M	0.50	0.45	M	0.50	0.45

TABLE V
Aggregation Matrix of a_1 and a_2

	a_1			a_2		
	μ	ν	π	μ	ν	π
c_1	0.85	0.09	0.06	0.81	0.13	0.06
c_2	0.86	0.08	0.06	0.51	0.44	0.05
c_3	0.84	0.10	0.06	0.77	0.16	0.07
c_4	0.67	0.27	0.07	0.72	0.21	0.07
c_5	0.79	0.15	0.06	0.76	0.18	0.06
c_6	0.69	0.23	0.07	0.67	0.27	0.07
c_7	0.63	0.32	0.05	0.64	0.29	0.07
c_8	0.81	0.13	0.06	0.66	0.28	0.05
c_9	0.54	0.39	0.07	0.71	0.22	0.07

TABLE VI
Weighted Aggregation Matrix for a_1 and a_2

	a_1			a_2		
	μ	ν	π	μ	ν	π
c_1	0.77	0.14	0.10	0.73	0.17	0.10
c_2	0.77	0.13	0.10	0.46	0.46	0.07
c_3	0.63	0.28	0.09	0.58	0.33	0.10
c_4	0.33	0.60	0.07	0.36	0.56	0.07
c_5	0.59	0.32	0.09	0.57	0.35	0.08
c_6	0.35	0.58	0.08	0.33	0.60	0.07
c_7	0.47	0.45	0.07	0.48	0.43	0.09
c_8	0.61	0.31	0.09	0.50	0.43	0.08
c_9	0.49	0.42	0.09	0.64	0.26	0.10

TABLE VII
Ideal intuitionistic fuzzy positive and negative solutions.

	c_1			c_2			$\cdots$	c_9		
	μ	ν	π	μ	ν	π	$\cdots$	μ	ν	π
A+	0.77	0.14	0.10	0.77	0.13	0.10	$\cdots$	0.64	0.26	0.10
A-	0.57	0.32	0.11	0.46	0.46	0.07	$\cdots$	0.22	0.74	0.04

[2] J.-J. Wang, Y.-Y. Jing, C.-F. Zhang, and J.-H. Zhao, "Review on multi-criteria decision analysis aid in sustainable energy decision-making," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 9, pp. 2263–2278, 2009.

[3] C.-L. Hwang and K. Yoon, *Methods for Multiple Attribute Decision Making*. Berlin, Heidelberg: Springer Berlin Heidelberg, 1981, pp. 58–191.

[4] L. A. Zadeh, "Information and control," *Fuzzy Sets*, vol. 8, no. 3, pp. 338–353, 1965.

TABLE VIII
POSITIVE DISTANCE OF a_1 AND a_2

	a_1			a_2		
	μ	ν	π	μ	ν	π
c_1	0.00	0.00	0.00	0.00	0.00	0.00
c_2	0.00	0.00	0.00	0.09	0.11	0.00
c_3	0.00	0.00	0.00	0.00	0.00	0.00
c_4	0.01	0.01	0.00	0.00	0.00	0.00
c_5	0.00	0.00	0.00	0.00	0.00	0.00
c_6	0.00	0.00	0.00	0.00	0.00	0.00
c_7	0.00	0.00	0.00	0.00	0.00	0.00
c_8	0.00	0.00	0.00	0.01	0.01	0.00
c_9	0.02	0.03	0.00	0.00	0.00	0.00

TABLE IX
NEGATIVE DISTANCE a_1 AND a_2

	a_1			a_2		
	μ	ν	π	μ	ν	π
c_1	0.04	0.03	0.00	0.02	0.02	0.00
c_2	0.09	0.11	0.00	0.00	0.00	0.00
c_3	0.12	0.14	0.00	0.09	0.11	0.00
c_4	0.07	0.10	0.00	0.08	0.12	0.00
c_5	0.07	0.08	0.00	0.06	0.07	0.00
c_6	0.04	0.05	0.00	0.03	0.04	0.00
c_7	0.05	0.06	0.00	0.05	0.07	0.00
c_8	0.11	0.12	0.00	0.05	0.05	0.00
c_9	0.07	0.10	0.00	0.17	0.23	0.00

TABLE X
RANKING OF WEB ACCESSIBILITY TEST TOOLS

Solution	S^+	S^-	RP_{A_i}	Ranking
a_1	0.062	0.287	0.822	1
a_2	0.118	0.269	0.694	2
a_3	0.185	0.197	0.516	5
a_4	0.303	0.042	0.122	6
a_5	0.175	0.192	0.523	4
a_6	0.115	0.253	0.689	3

[5] ——, "The concept of a linguistic variable and its application to approximate reasoning," *Information Sciences*, vol. 8, no. 3, pp. 199–249, 1975.

[6] S. H. Rubin, "Computing with words," *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*, vol. 29, no. 4, pp. 518–524, 1999.

[7] L. A. Zadeh, "Fuzzy logic= computing with words," *IEEE Transactions on Fuzzy Systems*, vol. 4, no. 2, pp. 103–111, 1996.

[8] R. Montes, A. Sánchez, P. Villar, and F. Herrera, "A web tool to support decision making in the housing market using hesitant fuzzy linguistic term sets," *Applied Soft Computing*, vol. 35, pp. 949–957, 2015.

[9] R. Montes, A. M. Sanchez, P. Villar, and F. Herrera, "Teranga go!: Carpooling collaborative consumption community with multi-criteria hesitant fuzzy linguistic term set opinions to build confidence and trust," *Applied Soft Computing*, vol. 67, pp. 941–952, 2018.

[10] J. Mendel, L. A. Zadeh, E. Trillas, R. R. Yager, J. Lawry, H. Hagras, and S. Guadarrama, "What computing with words means to me," *IEEE Computational Intelligence Magazine*, vol. 5, pp. 20–26, 2010.

[11] J. Morales, R. Montes, N. Zermeño, J. Duran, and F. Herrera, "The use of fuzzy linguistic information and fuzzy delphi method to validate by consensus a questionnaire in a blended-learning environment," in *Information Processing and Management of Uncertainty in Knowledge-Based Systems. Applications*. Springer International Publishing, 2018, pp. 137–149.

[12] K. T. Atanassov, "Intuitionistic fuzzy sets," *Fuzzy Sets and Systems*, vol. 20, no. 1, pp. 87–96, 1986.

[13] Z. Yue and Y. Jia, "A group decision making model with hybrid intuitionistic fuzzy information," *Computers & Industrial Engineering*, vol. 87, pp. 202–212, 2015.

[14] K. T. Atanassov, "Operators over interval valued intuitionistic fuzzy sets," *Fuzzy Sets and Systems*, vol. 64, no. 2, pp. 159–174, 1994.

[15] Z. Xu, "Intuitionistic fuzzy aggregation operators," *IEEE Transactions on Fuzzy Systems*, vol. 15, no. 6, pp. 1179–1187, 2007.

[16] F. E. Boran, S. Genç, M. Kurt, and D. Akay, "A multi-criteria intuitionistic fuzzy group decision making for supplier selection with topsis method," *Expert Systems with Applications*, vol. 36, no. 8, pp. 11 363–11 368, 2009.

[17] B. Rouyendegh, "Developing an integrated anp and intuitionistic fuzzy topsis model for supplier selection," *Journal of Testing and Evaluation*, vol. 43, no. 3, pp. 664–672, 2015.

[18] E. Afful-Dadzie, Z. K. Oplatkova, and L. A. B. Prieto, "Comparative state-of-the-art survey of classical fuzzy set and intuitionistic fuzzy sets in multi-criteria decision making," *International Journal of Fuzzy Systems*, vol. 19, no. 3, pp. 726–738, 2017.

[19] S. Shariati, M. Abedi, A. Saedi, A. Yazdani-Chamzini, J. Tamošaitienė, J. Šaparauskas, and S. Stupak, "Critical factors of the application of nanotechnology in construction industry by using anp technique under fuzzy intuitionistic environment," *Journal of Civil Engineering and Management*, vol. 23, no. 7, pp. 914–925, 2017.

[20] Y. Yuan, T. Guan, X. Yan, and Y. Li, "Based on hybrid vikor method decision making model for supplier selection," *Control and Decision*, vol. 29, no. 3, pp. 551–560, 2014.

[21] S. Ebrahimnejad, H. Hashemi, S. Mousavi, and B. Vahdani, "A new interval-valued intuitionistic fuzzy model to group decision making for the selection of outsourcing providers." *Economic Computation & Economic Cybernetics Studies & Research*, vol. 49, no. 2, 2015.

[22] B. Pardha Saradhi, N. R. Shankar, and C. Suryanarayana, "Novel distance measure in fuzzy topsis for supply chain strategy based supplier selection," *Mathematical Problems in Engineering*, vol. 2016, 2016.

[23] R. J. Kuo, C. W. Hsu, and Y. L. Chen, "Integration of fuzzy anp and fuzzy topsis for evaluating carbon performance of suppliers," *International Journal of Environmental Science and Technology*, vol. 12, no. 12, pp. 3863–3876, 2015.