An Evaluation Model with Unbalanced Linguistic Information Applied to Olive Oil Sensory Evaluation.

Article *in* Journal of Multiple-valued Logic and Soft Computing · January 2009

Source: DBLP

J. of Mult.-Valued Logic & Soft Computing, Vol. 15, pp. 229–250
Reprints available directly from the publisher
Photocopying permitted by license only

An Evaluation Model with Unbalanced Linguistic Information Applied to Olive Oil Sensory Evaluation

L. MARTÍNEZ[1], M. ESPINILLA[1], J. LIU[2], L.G. PÉREZ[1] AND P. J. SÁNCHEZ.[1]

[1]*Department of Computer Science, University of Jaén, 23071 – Jaén, Spain*
[2] *School of Computing and Mathematics, University of Ulster, BT37 0QB – Belfast, UK*
E-mail: martin@ujaen.es

Received: April 11, 2007. Accepted: March 20, 2008.

The evaluation processes are used for quality inspection, marketing and other fields in industrial companies. This paper focuses on sensory evaluation where the evaluated items are assessed by a panel of experts according to the knowledge acquired via human senses. In these evaluation processes, the information provided by the experts implies uncertainty, vagueness and imprecision. The use of the Fuzzy Linguistic Approach [28] has provided successful results modelling such a type of information. Usually these evaluation processes based on linguistic approaches have used symmetrical and uniformly distributed linguistic term sets in order to model the preferences about the evaluated objects. However, in sensory evaluation is common to find problems whose items or features need to be assessed with assessments in scales that one side of the scale overweight the another one, it means the use of a unbalanced linguistic scale. In this paper we present a sensory evaluation model that manages evaluation frameworks with unbalanced linguistic information. This model will be applied to the sensory evaluation process of Olive Oil that implies the definition of a proper framework adapted to the preference modelling of the proposed evaluation model.

Keywords: Sensory evaluation, unbalanced linguistic term sets, linguistic hierarchies, linguistic information.

1 INTRODUCTION

Evaluation is a complex cognitive process that involves different mechanisms in which it is necessary to define the elements to evaluate, fix the evaluation framework, gather the information and obtain an evaluation assessment by means of an evaluation process. The aim of any evaluation process is to obtain information about the worth of an item (product, service, material, etc.), a complete description of different aspects, indicators, criteria in order to improve it or to compare with other items to know which are the best ones. The information gathered in evaluation processes is usually provided by a group of individuals, called panel of experts, where each expert expresses his/her opinions about the evaluated items according to his/her own knowledge and perceptions.

In this paper we focus on *Sensory Evaluation* [12,21,24,25] that is an evaluation discipline where the information provided by the panel of experts, is perceived by the human senses of *sight, smell, taste, touch and hearing*.

When the experts' knowledge about the evaluated items, criteria, indicators, etc., is certain or such elements are quantitative in nature the assessments provided by the experts are usually numerical values [1,6]. On the other hand if their nature is qualitative or the experts' knowledge involves uncertainty and vagueness, such as it happens in sensory evaluation, the use of linguistic assessments have obtained successful results in different disciplines [2,4,7,10,13,15,18]. And the use of the fuzzy linguistic approach provides a direct way to represent linguistic information by means of linguistic variables. In the literature can be found many linguistic evaluation models and processes [7,8,11,21,22], but most of them use term sets with odd cardinality where the middle label means *indifference* and the rest of labels are symmetrical and uniformly distributed around it.

In [20] we have already presented a linguistic sensory evaluation model for olive oil, but during its deployment; we have detected that the use of symmetrical and uniformly linguistic term sets can bias the evaluation process. Due to the fact that the objective of evaluation process is, to find out the classification of an oil sample according to its features. But this classification depends more about the values obtained by such features in the left side of the scale than in the right side as we shall show in Section 5. Then linguistic scales as Fig. 1, can induce some biases in the evaluation because of the use of a finer granularity than the needed in fact. In order to avoid this situation we propose the use of Unbalanced Linguistic scales [14,26] as in Fig. 2, such that, there is a finer granularity in the side of the scale where it is required than in the another one.

The use of decision approaches have been successfully applied to solve evaluation problems in the literature [1,6,7,15,19,20]. In decision theory

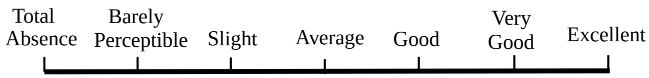

FIGURE 1
Symmetrical and uniformly distributed term set of 7 labels.

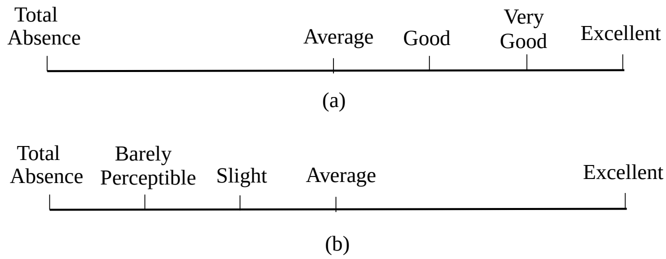

FIGURE 2
Unbalanced linguistic term set of 5 labels.

before making a decision is carried out a decision analysis process [9] that allows people to make decisions more consistently, i.e., it helps experts to deal with difficult decisions. The decision analysis is a suitable approach for evaluation processes because it helps to analyze the alternatives, criteria, indicators of the element/s under study that it is the objective of the evaluation processes.

Therefore, the aim of this paper is to propose an evaluation model based on a decision analysis approach dealing with unbalanced linguistic information without loss of information. In order to apply it to those problems whose necessities are better adapted to a unbalanced modelling. We shall show an application to olive oil sensory evaluation.

In order to do that, this paper is structured as follows: Section 2 revises the scheme of the Decision Analysis and introduces a linguistic background revising in short the fuzzy linguistic approach, the 2-tuple fuzzy linguistic representation model, and linguistic hierarchical contexts. Section 3 establishes the basic ideas for managing unbalanced linguistic term sets by using linguistic hierarchies. Section 4 proposes a Sensory Evaluation Model with Unbalanced Linguistic Information, that it is applied to the sensory evaluation of the olive oil in Section 5. Finally Section 6 points out some concluding remarks.

2 PRELIMINARIES

In this section we revise the scheme of the Decision Analysis in which our proposal of evaluation model will be based on and make a short review of linguistic background that presents different concepts that are necessary to manage linguistic information and to understand the proposed evaluation model.

2.1 Decision analysis

The Decision Analysis is a discipline, which belongs to Decision Theory, whose purpose is to help decision makers to reach a consistent decision in a

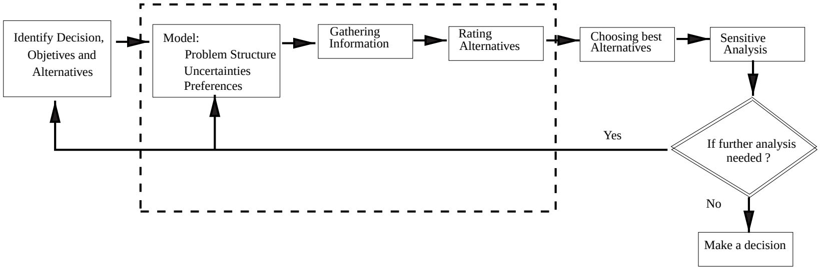

FIGURE 3
Decision analysis scheme.

decision making problem. The evaluation process can be modelled as different types of decision making problems, in this paper we model the evaluation process as a Multi-Expert Decision Making (MEDM) problem. In this type of decision problem, decision makers express their opinions about a set of alternatives, by means of an utility vector. A classical decision analysis scheme consists of the following phases (see Fig. 3):

- *Identify decision, objectives and alternatives of the problem.*
- *Model:* It defines the framework defining the structure of the problem, in our case modelled as a MEDM [17], and the expression domains in which the preferences can be assessed.
- *Gathering information:* decision makers provide their information.
- *Rating alternatives:* This phase obtains a collective value for each alternative.
- *Choosing best alternatives:* It selects the solution from the set of alternatives (applying a choice degree [3,23] to the collective values computed in the before phase).
- *Sensitive analysis:* the solution obtained is analyzed in order to know if it is good enough to make a decision, otherwise, go back initial phases to improve the the quality of the results.
- *Make a decision.*

The application of the decision analysis to an evaluation process does not imply all phases. The essential phases regarding an evaluation problem that will be used in our proposal for the evaluation model are those ones dashed in a rectangle of the Fig. 3.

2.2 Linguistic background

In order to manage unbalanced linguistic information in our proposal, we need some tools and concepts about linguistic information. Here, we review briefly the *Fuzzy Linguistic Approach*, the *2-tuple Linguistic representation model* and the *Linguistic Hierarchies*.

2.2.1 Fuzzy linguistic approach

Many aspects of different activities in the real world cannot be assessed in a quantitative form, but rather in a qualitative one, i.e., with vague or imprecise knowledge. In that case, a better approach may be the use of linguistic assessments instead of numerical values. The fuzzy linguistic approach represents qualitative aspects as linguistic values by means of linguistic variables [28].

We have to choose the appropriate linguistic descriptors for the term set and their semantics. In a linguistic approach an important parameter to determine is the "granularity of uncertainty", i.e., the cardinality of the linguistic term set used to express the information. One possibility of generating the linguistic term set consists of directly supplying the term set by considering all terms distributed on a scale on which a total order is defined [27]. For example, a set of seven terms S, could be:

$$\{s_0 : N, s_1 : VL, s_2 : L, s_3 : M, s_4 : H, s_5 : VH, s_6 : P\}$$

Usually, in these cases, it is required that in the linguistic term set there exist:

(1) A negation operator: $\mathrm{Neg}(s_i) = s_j$ such that $j = g - \mathrm{i}(g + 1$ is the cardinality).

(2) An order: $s_i \leq s_j \Longleftrightarrow i \leq j$. Therefore, there exists a min and a max operator.

The semantics of the terms are given by fuzzy numbers defined in the [0, 1] interval, which are usually described by membership functions. In this paper, we shall use as semantics of the linguistic terms triangular membership functions whose representation is achieved by a 3-tuple (a, b, c), where b indicate the point in which the membership value is 1, with a and c indicating the left and right limits of the definition domain of the membership function [5]. An example of uniformly linguistic term set may be:

$$\begin{array}{lll} P = (.83, 1, 1) & VH = (.67, .83, 1) & H = (.5, .67, .83) \\ M = (.33, .5, .67) & L = (.17, .33, .5) & VL = (0, .17, .33) \\ N = (0, 0, .17). & & \end{array}$$

which is graphically shown in Fig. 4.

2.2.2 2-tuple linguistic representation model

The use of linguistic information implies processes of Computing with Words (CW), in [16] was presented a linguistic representation model based on linguistic 2-tuples that carries out processes of CW in a precise way when the linguistic term sets are symmetrical and uniformly distributed. This model is based on the concept of symbolic translation.

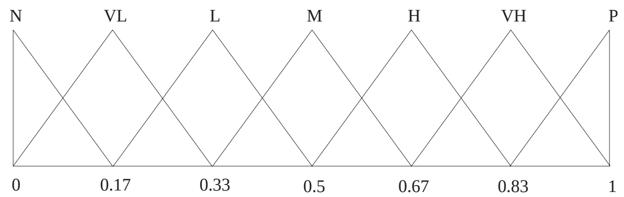

FIGURE 4
A set of 7 terms with its semantic.

The 2-tuple fuzzy linguistic representation model represents the linguistic information by means of a 2-tuple, (s, α), where s is a linguistic label and α is a numerical value that represents the value of the symbolic translation.

Definition 1 ([16]). Let β be the result of an aggregation of the indices of a set of labels assessed in a linguistic term set S, i.e., the result of a symbolic aggregation operation. $\beta \in [0, g]$, being $g + 1$ the cardinality of S. Let $i = round(\beta)$ and $\alpha = \beta - i$ be two values, such that, $i \in [0, g]$ and $\alpha \in [-.5, .5)$ then α is called a *Symbolic Translation*.

This linguistic representation model defines a set of functions to make transformations between linguistic 2-tuples and numerical values.

Definition 2 ([16]). Let $S = \{s_0, \ldots, s_g\}$ be a linguistic term set and $\beta \in [0, g]$ a value supporting the result of a symbolic aggregation operation, then the 2-tuple that expresses the equivalent information to β is obtained with the following function:

$$\Delta : [0, g] \longrightarrow S \times [-0.5, 0.5)$$

$$\Delta(\beta) = \begin{cases} s_i & i = round(\beta) \\ \alpha = \beta - i & \alpha \in [-.5, .5) \end{cases}$$

where *round* is the usual *rounding* operation, s_i has the closest index label to "β" and "α" is the value of the symbolic translation.

We note that Δ is bijective and $\Delta^{-1} : S \times [-.5, .5) \longrightarrow [0, g]$ is defined by $\Delta^{-1}(s_i, \alpha) = i + \alpha$. In this way, the 2-tuples of $S \times [-.5, .5)$ will be identified with the numerical values in the interval $[0, g]$

Remark 1. From definitions 1 and 2, it is obvious that the conversion of a linguistic term into a linguistic 2-tuple consist of adding a value 0 as symbolic translation:

$$s_i \in S \Longrightarrow (s_i, 0).$$

The 2-tuple representation model has associated a computational model presented in detail in [16].

2.2.3 Linguistic hierarchies

The hierarchical linguistic structure was used in [17] to improve the precision of the processes of CW in linguistic multi-granular contexts. We review it, because it is utilized to keep the precision of the processes of CW dealing with unbalanced linguistic term sets.

A *linguistic hierarchy* is a set of levels, where each level is a linguistic term set with different granularity from the remaining of levels of the hierarchy. Each level belonging to a linguistic hierarchy is denoted as $\mathbf{l}(\mathbf{t}, \mathbf{n}(\mathbf{t}))$, being:

(1) t, indicates the level of the hierarchy,

(2) *n(t)*, the granularity of the linguistic term set of the level t.

It is assumed hierarchical levels containing linguistic terms whose membership functions are triangular-shaped, symmetrical and uniformly distributed in [0, 1]. In addition, the linguistic term sets have an odd number of elements. The levels belonging to a linguistic hierarchy are ordered according to their granularity. For any two consecutive levels t and $t+1$, $n(t+1) > n(t)$. This provides a linguistic refinement of the previous level.

From the above concepts, we define a linguistic hierarchy, LH, as the union of all levels $t : LH = \bigcup_t l(t, n(t))$

Given a LH, $S^{n(t)}$, denotes the linguistic term set of LH corresponding to the level t of LH with a granularity of uncertainty of $n(t) : S^{n(t)} = \{s_0^{n(t)}, \ldots, s_{n(t)-1}^{n(t)}\}$

Generally, we can say that the linguistic term set of level $t+1$, $S^{n(t+1)}$, is obtained from its predecessor, $S^{n(t)}$, as: $l(t, n(t)) \rightarrow l(t+1, 2 \cdot n(t) - 1)$

A graphical example of a linguistic hierarchy is showed in Fig. 5.

In [17] was defined a transformation function, $TF_{t'}^{t}$, between labels from different levels to carry out processes of CW in multi-granular linguistic

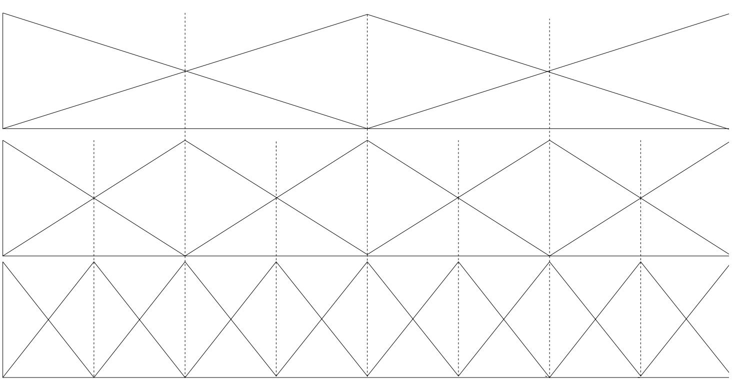

FIGURE 5
Linguistic Hierarchy of 3,5 and 9 labels.

information contexts without loss of information, as follows:

$$TF_{t'}^{t} : l(t, n(t)) \longrightarrow l(t', n(t'))$$

$$TF_{t'}^{t}(s_i^{n(t)}, \alpha^{n(t)}) = \Delta \left(\frac{\Delta^{-1}(s_i^{n(t)}, \alpha^{n(t)}) \cdot (n(t') - 1)}{n(t) - 1} \right)$$

In [17] was proof that, $TF_t^{t'}$ is bijective, then the transformations between levels of a linguistic hierarchy are carried out without loss of information.

3 UNBALANCED LINGUISTIC INFORMATION

Most of problems that model their information by using linguistic labels, assess their linguistic variables in linguistic term sets whose, terms are uniform and symmetrically distributed [7,8,21]. However, there exist many problems, such as olive oil sensory evaluation, in which it is more suitable to assess the assessments by means of linguistic term sets that are not uniform either symmetrically distributed. We call this type of term sets as, *unbalanced linguistic term sets* [14,26]. In some cases, the unbalanced linguistic information appears either due to the nature of the linguistic variables that participate in the problem, or in problems dealing with scales in which it is necessary to assess preferences with a finer granularity on a side of the scale than on the other one (see Fig. 2).

In [14] was presented in depth a methodology to deal with unbalanced linguistic information based on two elements:

(1) An algorithm that obtains the semantics for an unbalanced term set, S, for Fig. 2(a) by using triangular membership functions, $LH(S)$ computed from a Linguistic Hierarchy, LH (see Fig. 6 and Table 1): Additionally the algorithm provides a boolean function, $Brid(S)$, that will be used in the processes of CW.

(2) A computational model to accomplish processes of CW with unbalanced linguistic information in a *precise way* based on the 2-tuple computational model and the transformation functions of the Linguistic Hierarchies. Therefore, two unbalanced transformation functions were introduced to convert an unbalanced linguistic term, $s_i \in S$, into a linguistic term in the LH, $s_k^{n(t)} \in LH = \bigcup_t l(t, n(t))$ using the 2-tuple computational model.

 (a) $\mathfrak{LH}$: It is a transformation function that associates with each unbalanced linguistic 2-tuple (s_i, α), $s_i \in S$, its respective linguistic 2-tuple in LH $(s_k^{n(t)}, \alpha)$, $s_k^{n(t)} \in LH$.

$$\mathfrak{LH} : (S \times [0.5, -0.5)) \rightarrow (LH \times [0.5, -0.5)),$$

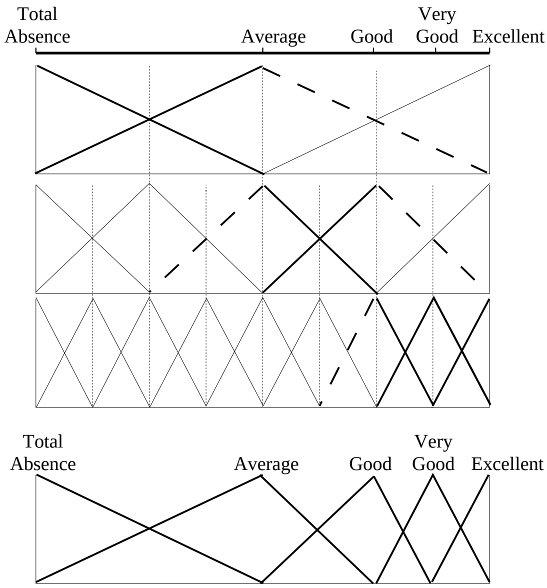

FIGURE 6
Semantic representation of a unbalanced linguistic term set.

S	$LH(S)$	$Brid(S)$
$s_0 = Poor$	$s^{G(0)}_{I(0)} = s^3_0$	False
$s_1 = Average$	$s^{G(1)}_{I(1)} = s^3_1$	True
$s_2 = Good$	$s^{G(2)}_{I(2)} = s^5_3$	True
$s_3 = Very\ Good$	$s^{G(3)}_{I(3)} = s^9_7$	False
$s_4 = Excellent$	$s^{G(4)}_{I(4)} = s^9_8$	False

TABLE 1
$LH(S)$ and $Brid(S)$

such that, $\forall (s_i, \alpha_i) \in (S \times [0.5, -0.5)) \implies \mathfrak{LH}(s_i, \alpha_i) = (s^{G(i)}_{I(i)}, \alpha_i)$.

(b) $\mathfrak{LH}^{-1}$: Transformation function that associates with each linguistic 2-tuple expressed in LH its respective unbalanced linguistic 2-tuple in S.

$$\mathfrak{LH}^{-1} : (LH \times [0.5, -0.5)) \to (S \times [0.5, -0.5)),$$

being t a level of LH, then it was defined by cases see [14].

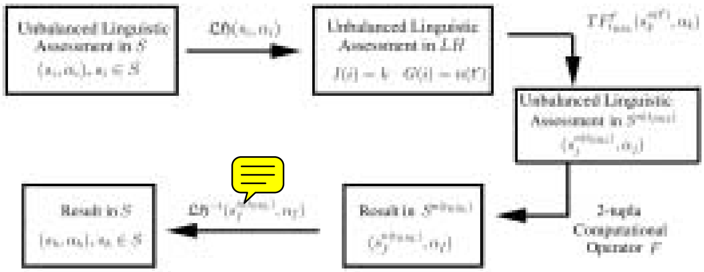

FIGURE 7
Scheme of an aggregation operator of unbalanced linguistic information.

A further detailed description of the algorithm an computational model for unbalanced linguistic term sets can be found in [14].

The unbalanced linguistic computational model defines a comparison operator, a negation operator and a tool for aggregating unbalanced linguistic information. These operators use the transformation functions, $\mathfrak{LH}$ and $\mathfrak{LH}^{-1}$ and its operational scheme can be seen in Fig. 7. That will be used and explained in further detail in the following section.

4 SENSORY EVALUATION MODEL DEALING WITH UNBALANCED LINGUISTIC INFORMATION

The aim of this paper is to present a Sensory Evaluation model based on the linguistic decision analysis [9] to deal with unbalanced linguistic information. In order to obtain an evaluation framework where the experts can express their preferences in unbalanced linguistic term sets with different discrimination levels on both sides of the scale, and the processes of CW can be carried out without loss of information. Such that, we can apply it to the olive oil sensory evaluation process.

The decision analysis scheme that will use our proposal for the sensory evaluation model consists of the following phases (graphically, Fig. 8) revised in Section 2.1:

- *Identify Evaluated Objects*.
- *Evaluation Framework*.
- *Gathering Information*.
- *Rating Objects*.
- *Evaluation Results*.

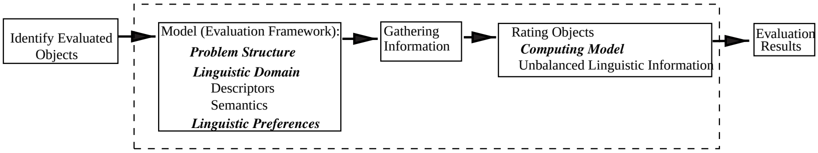

FIGURE 8
Sensory Evaluation Scheme based on linguistic 2-tuple decision analysis.

The following subsections present in detail the main phases of the above linguistic sensory evaluation model.

4.1 Evaluation framework

In this phase it is defined the evaluation framework, such that, it is fixed the problem structure, the linguistic descriptors and semantics that will be used by the panel of experts to provide their assessments about the evaluated objects.

Due to the fact that, our interest is focused on sensory evaluation problems dealing with unbalanced linguistic information in which, the experts need a greater level of distinction in one side of the evaluation scale than in the other one. We propose an unbalanced linguistic evaluation framework based on a MEDM problem structure where, the experts can express their opinions by means of labels belonging to unbalanced linguistic term sets [14]. In such a case, all the experts provide their sensory subjective preferences using one unbalanced linguistic term set. Hence the evaluation framework will be as the following one:

$E = \{e_1, \ldots, e_n\}$, a panel of experts.

$S = \{s_0, \ldots, s_g\}$, unbalanced linguistic term set.

$X = \{x_1, \ldots, x_m\}$ set of items to be evaluated sensorially.

$F = \{f_1, \ldots, f_h\}$ set of sensory features that characterizes each evaluated item x_i

Once the unbalanced term set, S, has been fixed. Its semantics will be obtained applying the algorithm for representing the unbalanced labels (see Fig. 12). Furthermore, the algorithm provides information to manage the processes of CW.

This framework facilitates the modelling of unbalanced assessments in evaluation processes and the computing processes with such a type of information.

4.2 Gathering information

Once the framework has been defined in order to evaluate the different items, the evaluation process must obtain the knowledge from the panel of experts.

Given that, the framework has been fixed with a MEDM [17] problem structure, the experts will provide their knowledge by using utility vectors that contain a linguistic assessment for each evaluated feature. Each expert, e_i provides his/her preferences in S by means of an utility vector:

$$U_i = \{u^i_{11}, \dots, u^i_{1h}, u^i_{21}, \dots, u^i_{2h}, \dots, u^i_{m1}, \dots, u^i_{mh}\}$$

where $u^i_{jk} \in S$ is the assessment provided to the feature f_k of the item x_j by the expert e_i.

Consequently, in the gathering process every expert e_i will provide his/her utility vector U_i expressed by linguistic labels in the unbalanced linguistic term set, S, fixed in the evaluation framework.

4.3 Rating objects

The aim of the sensory evaluation process is to obtain information about the worth of an evaluated item. So, this phase of the evaluation model computes a global value for each item according to the information gathered. In order to operate with the unbalanced linguistic labels, this model will use the unbalanced linguistic computing model [14]. The linguistic preferences provided by the experts will be transformed into linguistic 2-tuples (by using the *Remark 1*:$u^i_{jk} \Rightarrow (u^i_{jk}, 0)$). Then, according to the computational scheme showed in the Fig. 7 these 2-tuples will be transformed into linguistic values in the LH by means of $\mathfrak{LH}$.

In fact, the semantics of the unbalanced term set, $LH(S)$, will belong to different levels of the LH, then we cannot operate directly with the information gathered. So we will conduct these labels into an unique level of the LH, called *Basic Representation Level* and noted as t_{BRL} which will support the computational processes of unbalanced linguistic assessments [17]. We choose t_{BRL}, as the level of LH used in the representation algorithm which has associated the highest granularity. The experts' preferences, $(u^i_{jk}, \alpha) \in S \times [-0.5, 0.5)$, are transformed into linguistic 2-tuples in $S^{n(t_{BRL})}$ by means of $\mathfrak{LH}$ that uses the transformation function, $TF^t_{t_{BRL}}$. A graphical example of the whole unification process for an unbalanced linguistic label can be seen in Fig. 9.

Once the information has been conducted into one expression domain, $S^{n(t_{BRL})}$, it is applied a two-step aggregation process to compute a global evaluation for the evaluated item:

(1) *Computing collective evaluations for each feature*: first, the rating process will compute a collective linguistic 2-tuple, (u_{jk}, α), for each feature, f_k, of the object x_j, using an aggregation operator, $AGOP_1$, on the assessments provided by the experts represented in t_{BRL}:

$$(u_{jk}, \alpha) = AGOP_1((u^1_{jk}, \alpha_1), \dots, (u^n_{jk}, \alpha_n)), u_{jk} \in S^{n(t_{BRL})}$$

(2) *Computing a collective evaluation for each object*: the final aim of the rating process is to obtain a global evaluation, (u_j, α), for each

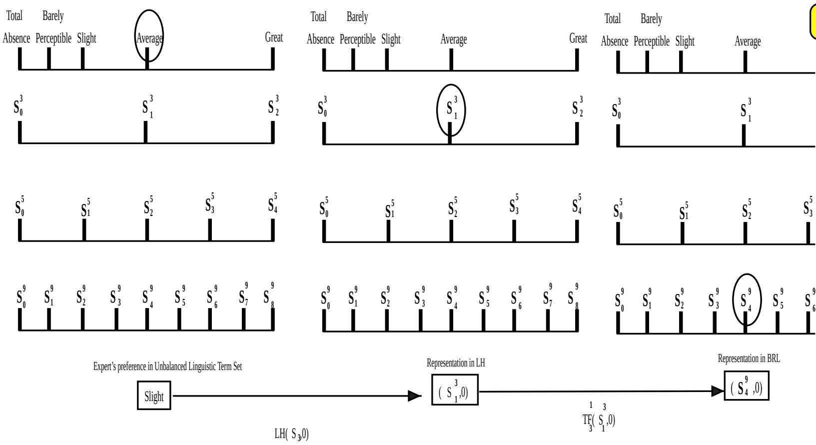

FIGURE 9
Semantic representation of the sensory evaluation in LH.

evaluated object, x_j, according to all the experts and all features that take part in the sensory evaluation process. To do so, this process will aggregate the collective linguistic 2-tuples for each object by using an aggregation operator, $AGOP_2$:

$$(u_j, \alpha) = AGOP_2((u_{j1}, \alpha_1), \ldots, (u_{jh}, \alpha_h)), u_j \in S^{t_{BRL}}$$

The aggregation operators, $AGOP_1$ and $AGOP_2$, could be the same or different ones depending on each sensory evaluation problem.

The aggregation results, will be obtained in $S^{n(t_{BRL})}$ and our model aim is to express them in the initial expression domain, i.e., the unbalanced linguistic term set S. To do so, the model will apply the transformation function $TF_t^{t_{BRL}}$ in $\mathfrak{LH}^{-1}$ to the results, (u_j, α), obtained by $AGOP_2$.

5 OLIVE OIL SENSORY EVALUATION

The virgin olive oil is distinguished of the rest of vegetal oils, because, its special organoleptical properties of color, scent and flavor. The evaluation of their organoleptical properties of scent and flavor are determined by means of the application of the sensorial analysis. The sensory evaluation is used as measure of quality of the oil and identifies their different categories (virgin extra, virgin, ordinary virgin or lampante)[1].

Currently, the classification of virgin olive oil samples is made according to the intensity of the defects and positive attributes (see Table 2) by a group

[1] URL:http://www.internationaloliveoil.org/downloads/orga6.pdf.

Negative attributes	Positive attributes
Fusty	Fruity
Musty-Humid	
Muddy sediment	
Wine-Vinegary	
Metallic	
Rancid	

TABLE 2
Attributes of olive oil

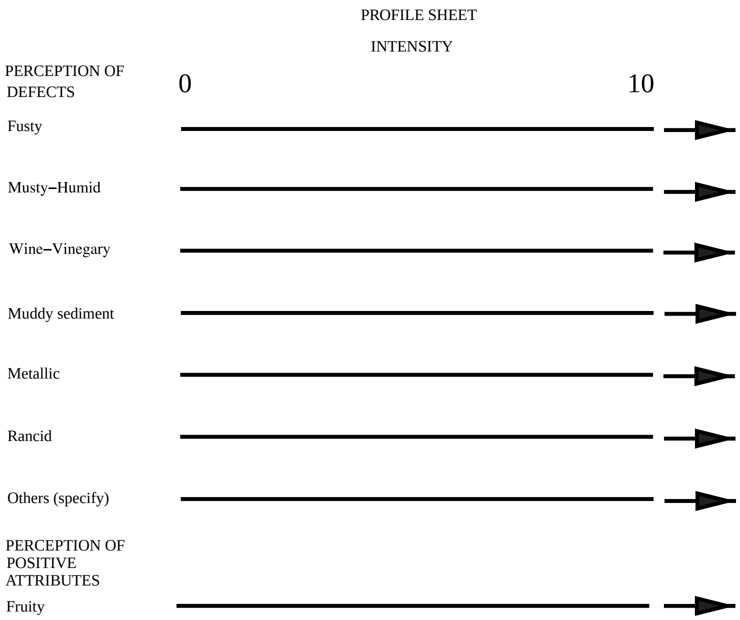

FIGURE 10
Profile sheet.

of experts selected and trained as a panel, other attributes can be used for other categorizations but, they are not used in this classification. The experts fill up the profile sheet, showed in Fig. 10, with quantitative values according to the intensity of their perceptions about each of the negative and positive attributes.

According to the intensity of the defects and positive attributes of the olive oil, it will be classified as:

(1) *Extra Virgin* grade when the median of the defects is equal to 0 and the median of the fruity attribute is more than 0.

(2) *Virgin* grade when the median of the defects is more than 0 and less than or equal to 2.5 and the median of the fruity attribute is more than 0.

(3) *Ordinary Virgin* grade when the median of the defects is more than 2.5 and less than or equal to 6.0 or when the median of the defects is less than or equal to 2.5 and the median of the fruity attribute is equal to 0.

(4) *Lampante virgin* grade when the median of the defects is more than 6.0.

Therefore, in the numerical scale and as we shall show later in the linguistic one too, we can point out that the classifier needs a finer granularity in the left side of the scale because the classification constraints (1)–(4) focus on those values in order to classify the olive oil samples.

Our aim is to define a proper qualitative framework for the olive oil sensory evaluation, taking into account that, the evaluated properties (see Table 2) are better adapted to an unbalanced scale with a finer granularity in the left side. We shall propose an unbalanced linguistic framework for this evaluation process and apply the model proposed in section 4, to classify olive oil samples in such an evaluation framework.

5.1 Unbalanced linguistic evaluation framework

First, we have to define the framework based on unbalanced linguistic information to evaluate olive oil samples. After a survey with different connoisseurs, the scale utilized to assess in a qualitative way the intensity of attributes are modelled by a unbalanced linguistic term set with five labels with the following syntax and distribution (see Fig. 11):

$$S = \{\textit{Total Absence},\ \textit{Barely Perceptible},\ \textit{Slight},\ \textit{Average},\ \textit{Great}\}$$

In order to understand easily so the framework as the remaining phases of the model. Let's suppose an Olive Oil Tasting Panel of eight connoisseurs $E = \{e_1, \ldots, e_8\}$ will evaluate the intensity of the negative attributes: *Fusty, Musty-Humid, Muddy sediment, Wine-Vinegary, Metallic, Rancid* and the positive one *Fruity*. These attributes will be noted as, $F = \{f_1, \ldots, f_7\}$, set of sensorial attributes for a sample of Olive Oil.

Applying the representation algorithm of unbalanced linguistic information to model the unbalanced term S using the LH showed in Fig.5. The algorithm provides the semantic representation showed in Fig. 12 and the $LH(S)$ and $Brid(S)$, which are given in Table 3.

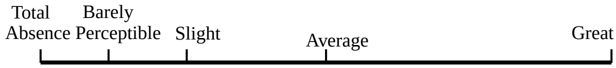

FIGURE 11
Semantic representation of the sensory evaluation in LH.

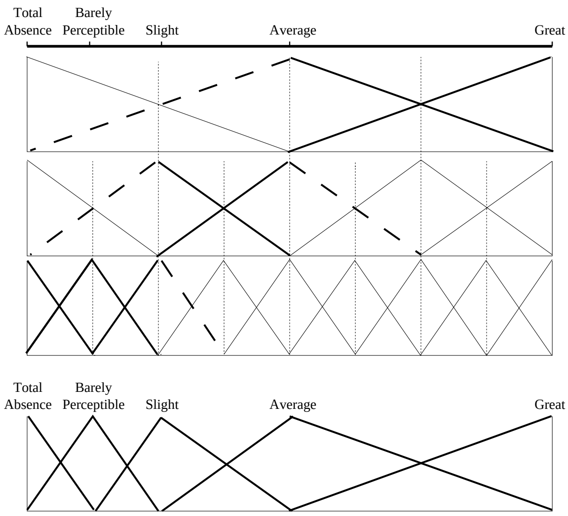

FIGURE 12
Semantic representation of the sensory evaluation in LH.

S	$LH(S)$	$Brid(S)$
$s_0 = \mathit{Total\ Absence}$ (TA)	$s^{G(0)}_{I(0)} = s^9_0$	False
$s_1 = \mathit{Barely\ Perceptible}$ (BP)	$s^{G(1)}_{I(1)} = s^9_1$	False
$s_2 = \mathit{Slight}$ (S)	$s^{G(2)}_{I(2)} = s^5_1$	True
$s_3 = \mathit{Average}$ (A)	$s^{G(3)}_{I(3)} = s^3_1$	True
$s_4 = \mathit{Great}$ (G)	$s^{G(4)}_{I(4)} = s^3_2$	False

TABLE 3
$LH(S)$ and $Brid(S)$

The semantics and syntax of the linguistic term set used in the evaluation process are:

$$s_0 = \mathit{Total\ Absence} = (0, 0, .125),\ s_1 = \mathit{Barely\ Perceptible} = (0, .125, .25)$$
$$s_2 = \mathit{Slight} = (.125, .25, .5),\ s_3 = \mathit{Average} = (.25, .5, 1),$$
$$s_4 = \mathit{Great} = (.5, 1, 1)$$

5.2 Gathering information

In our qualitative framework, the experts of the Tasting Panel provide their preferences about the attributes of the Table 2. In Table 4 we can see the preferences provided by our panel. These preferences are provided by filling the form showed in the Fig. 13:

	f_1	f_2	f_3	f_4	f_5	f_6	f_7
e_1	*TA*	*TA*	*TA*	*TA*	*TA*	*TA*	*A*
e_2	*TA*	*TA*	*TA*	*TA*	*TA*	*TA*	*S*
e_3	*TA*	*TA*	*TA*	*TA*	*TA*	*TA*	*S*
e_4	*TA*	*TA*	*TA*	*TA*	*TA*	*TA*	*S*
e_5	*TA*	*TA*	*TA*	*TA*	*TA*	*TA*	*S*
e_6	*TA*	*TA*	*TA*	*TA*	*TA*	*TA*	*A*
e_7	*TA*	*TA*	*TA*	*TA*	*TA*	*TA*	*G*
e_8	*TA*	*TA*	*TA*	*TA*	*TA*	*TA*	*G*

TABLE 4
Olive oil tasting panel's utility vectors for the attributes

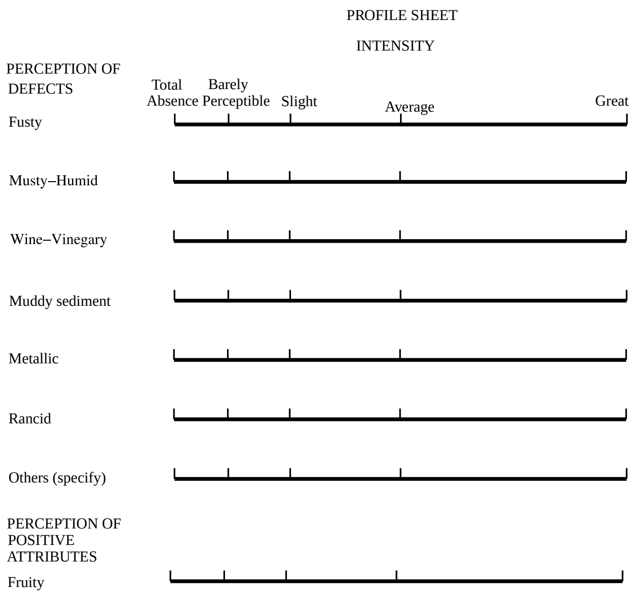

FIGURE 13
Profile sheet.

Due to the fact that, we are dealing with an unbalanced linguistic framework the experts preferences will be transformed into 2-tuple representation model using the symbolic representation s_i instead of its syntax to manage easily this information, the results of this transformation is showed in Table 5.

5.3 Rating objects

The classification of olive oil samples is carried out according to the intensity of the defects and the fruity. To do so and according to the proposed model, it is computed a collective value from the evaluated features. In our case the

	f_1	f_2	f_3	f_4	f_5	f_6	f_7
e_1	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_3, 0)$
e_2	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_2, 0)$
e_3	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_2, 0)$
e_4	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_2, 0)$
e_5	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_2, 0)$
e_6	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_3, 0)$
e_7	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_4, 0)$
e_8	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_4, 0)$

TABLE 5
Olive oil tasting panel's utility vectors for the feature the 2-tuple representation model

negative features and the fruity feature. In the quantitative model this collective value is computed by using the median operator, so in our proposal we shall extend the median operator to deal with linguistic 2-tuples that is defined as follows:

Definition 3. Let $X = \{(s_j, \alpha)_1, \ldots, (s_j, \alpha)_n\},\ s_j \in S = \{s_0, \ldots, s_g\}$ be an ordered set of 2-tuples and $(s_j, \alpha)_k$ is the k-th largest of the elements in X, the 2-tuple median operator $Med(X)$ is computed as,

$$Med(X) = \begin{cases} Med(X) = (s_j, \alpha)_{\frac{n+1}{2}} & \text{if } n \text{ is odd} \\ Med(X) = (s_j, \alpha)_{\frac{n}{2}} & \text{if } n \text{ is even} \end{cases}$$

When n is even the value of the median is not unique, $Med(X) \in [(s_j, \alpha)_{\frac{n}{2}}, (s_j, \alpha)_{\frac{n+1}{2}}]$. More generally:

$$Med(X) = \Delta\left(\frac{\Delta^{-1}(s_j, \alpha)_{\frac{n}{2}} + \Delta^{-1}(s_j, \alpha)_{\frac{n+1}{2}}}{2}\right)$$

Then, the rating process for this problem consists of two aggregation steps:

(1) *Computing collective evaluations for each feature*: We use the aggregation operator for 2-tuples Λ^F, being $F = Med(X)$ i.e., the median for 2-tuples defined above. In Table 6 we show the collective values obtained by the median.

	f_1	f_2	f_3	f_4	f_5	f_6	f_7
$\Lambda^F(f_i)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_0, 0)$	$(s_3, 0)$

TABLE 6
Collective values for each feature

An example of the computation of the median for the attribute positive fruity, f_7, is:

$$
\begin{aligned}
(s_3, 0) &= \Lambda^F[(s_3, 0), (s_2, 0), (s_2, 0), (s_2, 0), (s_2, 0), (s_3, 0),\\
&\qquad (s_4, 0), (s_4, 0)]\\
&= \mathfrak{LH}^{-1}[\Lambda^F(TF^{t'}_{t_{BRL}}(\mathfrak{LH}(s_3, 0)), TF^{t'}_{t_{BRL}}(\mathfrak{LH}(s_2, 0)),\\
&\qquad TF^{t'}_{t_{BRL}}(\mathfrak{LH}(s_2, 0)), TF^{t'}_{t_{BRL}}(\mathfrak{LH}(s_2, 0)),\\
&\qquad TF^{t'}_{t_{BRL}}(\mathfrak{LH}(s_2, 0)), TF^{t'}_{t_{BRL}}(\mathfrak{LH}(s_3, 0)),\\
&\qquad TF^{t'}_{t_{BRL}}(\mathfrak{LH}(s_4, 0)), TF^{t'}_{t_{BRL}}(\mathfrak{LH}(s_4, 0)))]
\end{aligned}
$$

Being,

$$t_{BRL} = \max\{3, 2, 1, 1\} = 3$$

and

$$
\begin{aligned}
\mathfrak{LH}(s_3, 0) &= s_1^{n(1)} = s_1^3,\\
\mathfrak{LH}(s_2, 0) &= s_1^{n(2)} = s_1^5,\\
\mathfrak{LH}(s_4, 0) &= s_2^{n(2)} = s_2^5,
\end{aligned}
$$

then,

$$
\begin{aligned}
&\Lambda^F[(s_3, 0), (s_2, 0), (s_2, 0), (s_2, 0), (s_2, 0), (s_3, 0), (s_4, 0), (s_4, 0)]\\
&\quad = \mathfrak{LH}^{-1}[\Lambda^F((TF^1_3((s_1^3, 0)), TF^2_3((s_1^5, 0)), TF^2_3((s_1^5, 0)),\\
&\qquad\quad TF^2_3((s_1^5, 0)), TF^2_3((s_1^5, 0)), TF^1_3((s_1^3, 0)), TF^2_3((s_2^5, 0)),\\
&\qquad\quad TF^2_3((s_2^5, 0))))]\\
&\quad = \mathfrak{LH}^{-1}[\Lambda^F((s_4^9, 0), (s_2^9, 0), (s_2^9, 0), (s_2^9, 0), (s_2^9, 0), (s_4^9, 0),\\
&\qquad\quad (s_8^9, 0), (s_8^9, 0)]\\
&\quad = \mathfrak{LH}^{-1}(s_3^9, 0) = (s_3, 0)
\end{aligned}
$$

(2) *Computing a collective evaluation for each object*: in the olive oil sensory evaluation this process obtains two different values. One for the negative features, noted as d, and another one noted as p for the fruity attribute. Those values are computed as:

$$d = \max(g_1, \dots, g_n),$$

being $g_i = \Lambda^F(f_i)$, the median for the negative features $f_i, i \in \{1, 2, 3, 4, 5, 6\}$. And

$$p = \Lambda^F(f_7),$$

the median for the fruity feature. From these values the olive oil sample will be classified according to the classifier, $cl(x, y)$, that uses the values d and p as follows:

$$cl(d,p) = \begin{cases} \textit{extra virgin} & d = (s_0, 0) \quad \text{and} \quad p > (s_0, 0) \\ \textit{virgin} & (d > (s_0, 0) \quad \text{and} \quad d \leq (s_2, 0)) \quad \text{and} \\ & p > (s_0, 0) \\ \textit{ordinary virgin} & (s_2, 0) < d <= (s_3, 0.1) \quad \text{or} \\ & d <= (s_2, 0) \quad \text{and} \quad p = (s_0, 0) \\ \textit{lampante virgin} & d > (s_3, 0.1) \end{cases}$$

In our example:

$$d = (s_0, 0) = \max\{(s_0, 0), (s_0, 0), (s_0, 0), (s_0, 0), (s_0, 0), (s_0, 0)\},$$

and $p = (s_3, 0)$ then

$$cl((s_0, 0), (s_3, 0)) \Rightarrow \textit{extra virgin}.$$

The classification for the sample of olive oil is *extra virgin*.

6 CONCLUDING REMARKS

The sensory evaluation is a process in which the information provided by the experts involves uncertainty because it is acquired via human senses. Therefore, the use of linguistic information to model its variables can provide a suitable framework to deal with such uncertainty. Usually in such a case, uniform and symmetrically distributed term sets are used to assess the linguistic variables. However, we can find sensory evaluation problems in which the experts need a greater level of distinction in one side of the evaluation scale than in the another one. In this paper, we have presented a sensory evaluation model that offers an unbalanced linguistic evaluation framework to the experts in order to model linguistic scales for the evaluation process that are not symmetrical either uniformly distributed. And it provides an evaluation model that is able to deal with this type of information without loss of information.

ACKNOWLEDGEMENTS

This paper has been partially supported by the "Secretaría de Estado de Universidades e Investigación del MEC" PR2007-0250 and by the research project TIN2006-02121 and FEDER Funds.

REFERENCES

[1] J. Antes, L. Campen, U. Derigs, C Titze and G.D. Wolle. A model-based decision support system for the evaluation of flight schedules for cargo airlines. *Decision Support Systems* **22**(4) (1998), 307–323.

[2] B. Arfi. Fuzzy decision making in politics: A linguistic fuzzy-set approach (lfsa). *Political Analysis* **13**(1) (2005), 23–56.

[3] K. J. Arrow. *Social Choice and Individual Values*. Yale University Press, New Haven CT, 1963.

[4] D. Ben-Arieh and C. Zhifeng. Linguistic labels aggregation and consensus measure for autocratic decision-making using group recommendations. *IEEE Transactions on Systems, Man, and Cybernetics Part A – Systems and Humans*, page In Press, 2006.

[5] P. P. Bonissone and K.S. Decker. *Selecting Uncertainty Calculi and Granularity: An Experiment in Trading-Off Precision and Complexity*. In L.H. Kanal and J.F. Lemmer (eds.), Uncertainty in Artificial Intelligence. North-Holland, 1986.

[6] D. Bouyssou, T. Marchant, M. Pirlot, P. Perny, and A. Tsoukia‘s. *Evaluation and Decision Models: A critical perspective*. Kluwer Academic Publishers, 2000.

[7] C. T. Chen. Applying linguistic decision-making method to deal with service quality evaluation problems. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems* **9**(Suppl.) (2001), 103–114.

[8] C. H. Cheng and Y. Lin. Evaluating the best main battle tank using fuzzy decision theory with linguistic criteria evaluation. *European Journal of Operational Research* **142** (2002), 174–186.

[9] R. T. Clemen. *Making Hard Decisions. An Introduction to Decision Analysis*. Duxbury Press, 1995.

[10] G. Devedzic. Linguistic and choquet integral based evaluation in process planning. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems* **9**(Suppl.) (2001), 115–127.

[11] G. B. Devedzic and E. Pap. Multicriteria-multistages linguistic evaluation and ranking of machine tools. *Fuzzy Sets and Systems* **102** (1999), 451–461.

[12] G. B. Dijksterhuis. *Multivariate Data Analysis in Sensory and Consumer Science, Food and Nutrition*. Press Inc. Trumbull, Connecticut, USA, 1997.

[13] F. Herrera and E. Herrera-Viedma. Linguistic decision analysis: Steps for solving decision problems under linguistic information. *Fuzzy Sets and Systems* **115** (2000), 67–82.

[14] F. Herrera, E. Herrera-Viedma and L. Martínez. A fuzzy linguistic methodology to deal with unbalanced linguistic term sets. *IEEE Transactions on Fuzzy Systems*, page In press, 2008.

[15] F. Herrera, E. Herrera-Viedma, L. Martinez, F. Mata and P. J. Sanchez. *A Multi-Granular Linguistic Decision Model for Evaluating the Quality of Network Services*. Intelligent Sensory Evaluation: Methodologies and Applications. Springer, Ruan Da, Zeng Xianyi (eds.), 2004.

[16] F. Herrera and L. Martínez. A 2-tuple fuzzy linguistic representation model for computing with words. *IEEE Transactions on Fuzzy Systems* **8**(6) (2000), 746–752.

[17] F. Herrera and L. Martínez. A model based on linguistic 2-tuples for dealing with multigranularity hierarchical linguistic contexts in multiexpert decision-making. *IEEE Transactions on Systems, Man and Cybernetics. Part B: Cybernetics* **31**(2) (2001), 227–234.

[18] V. N. Huynh and Y. Nakamori. A satisfactory-oriented approach to multiexpert decision-making with linguistic assessments. *IEEE Transactions On Systems Man And Cybernetics Part B-Cybernetics* **35**(2) (2005), 184–196.

[19] A. Jiménez, S. Ríos-Insua and A. Mateos. A decision support system for multiattribute utility evaluation based on imprecise assignments. *Decision Support Systems* **36**(1) (2003), 65–79.

[20] A. C. Marquez and C. Blanchar. A decision support system for evaluating operations investments in high-technology business. *Decision Support Systems* **41**(2) (2006), 472–487.

[21] L. Martínez. Sensory evaluation based on linguistic decision analysis. *International Journal of Aproximated Reasoning* **44**(2) (2007), 148–164.

[22] L. Martínez, J. Liu, and J. B. Yang. A fuzzy model for design evaluation based on multiple-criteria analysis in engineering systems. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems* **14**(3) (2006), 317–336.

[23] S. A. Orlovsky. Decision-making with a fuzzy preference relation. *Fuzzy Sets Systems* **1** (1978), 155–167.

[24] D. Ruan and X. Zeng (eds.). *Sensory Evaluation: Methodologies and Applications*. Springer, 2004.

[25] H. Stone and J. L. Sidel. *Sensory Evaluation Practice*. Academic Press Inc., San Diego, CA, 1993.

[26] V. Torra. Aggregation of linguistic labels when semantics is based on antonyms. *International Journal of Intelligent Systems* **16** (2001), 513–524.

[27] R. R. Yager. An approach to ordinal decision making. *International Journal of Approximate Reasoning* **12** (1995), 237–261.

[28] L. A. Zadeh. The concept of a linguistic variable and its applications to approximate reasoning. *Information Sciences, Part I, II, III* **8,8,9** (1975), 199–249, 301–357, 43–80.