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Fuzzy TODIM for ELICIT Information

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Abstract. The available information in some decision situations may be vague or imprecise, and the involvement of human experts, who usually manage qualitative information, results essential to address the underlying uncertainty in such contexts. However, human decision-makers are rationally bounded, particularly when the decision processes involve risk and uncertainty. To model human stakeholders' behavior in such situations, the TODIM method (Portuguese acronym for Interactive Multi-Criteria Decision-Making) based on the Prospect Theory was developed to address multi-criteria decision-making (MCDM) situations. Even though the classic TODIM method was adapted to manage fuzzy information and, consequently, to model uncertainty by using linguistic labels, that proposal neglected the management of more complex linguistic expressions able to represent the experts' hesitancy among several linguistic labels, which is quite common due to the increasing complexity of decision problems. Therefore, this contribution introduces a multi-criteria group decision-making (MCGDM) model based on fuzzy TODIM dealing with Extended Comparative Linguistic Expressions with Symbolic Translation (ELICIT) values, which were recently proposed to model such hesitancy and perform precise computations without losing the interpretability of linguistic information.

Keywords: Linguistic TODIM · ELICIT information · Linguistic multi-criteria decision-making

1 Introduction

Even though the use of decision models based on the analysis of data is quite demanded in today society, some real-world problems still require the use of human experts to provide their knowledge and make decisions, especially in

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those situations in which the available data is vague or inaccurate [9]. In addition, including several experts' points of view improves the decision process when facing complex situations which require a quick response. In this context, MCGDM models become essential to face such situations in which human experts' knowledge is used to rate the considered alternatives under different criteria when the latter cannot be provided as objective values, but qualitative assessments. In this sense, preference modelling by means of linguistic information has become a milestone because of the flexibility that offers to the experts and its closeness to their natural way of thinking [7, 12]. Among other proposals to model experts' assessments by using the linguistic information [9], ELICIT information [7] has been recently proposed to provide precise computations with linguistic terms [11] and model experts' hesitancy.

In addition to uncertainty and hesitancy, decision solving processes also require considering humans' behavior when their decisions may imply significant losses, either economical, material or even human. Such a behavior was analyzed in Prospect Theory [6], which received the Nobel Prize for Economics in 2002. This theory is based on four main aspects: (i) the evaluation of gains and losses from a reference point (ii) the existence of a greater sensibility to losses than to gains (iii) the aversion to losses (iv) and the tendency to overestimate the occurrence of an unlikely event and underestimate those very likely.

In this contribution, it is proposed a MCGDM model based on ELICIT information and TODIM method [1, 3], which manages humans' behavior under risk circumstances and relies on Prospect Theory [6]. The main features of this ELICIT-TODIM model are:

1. It allows solving MCGDM problems by using qualitative information provided by human experts.
2. Uncertainty and experts' hesitancy are modelled by using ELICIT information.
3. It considers the use of Prospect Theory to model human behavior towards gains and losses.

The rest of this contribution is broken down into the following sections. Section 2 introduces the basic concepts related to the proposal. Section 3 presents the ELICIT-TODIM, whose performance is shown in the resolution of a MCGDM problem in Sect. 4. Finally, some conclusions and future researches are drawn in Sect. 5.

2 Background

To facilitate the understanding of the proposal, this section reviews the basic concepts regarding linguistic MCGDM and the 2-tuple and ELICIT linguistic representation models.

2.1 Linguistic Multi-criteria Group Decision-making

Formally, a MCGDM problem is defined by a set of experts $E = \{e_1, e_2, \dots, e_m\}$ who rate a predefined set of alternatives/options $A = \{a_1, a_2, \dots, a_n\}$ on several criteria $C = \{c_1, c_2, \dots, c_r\}$ [5]. Under circumstances in which experts feel more confident by providing their assessments over the alternatives by means of linguistic expressions, we can talk about linguistic MCGDM. In MCGDM, the experts' preferences are usually collected in preference structures, so-called decision matrices. A decision matrix is defined as, $D = (d_{ij})_{n \times r}$ whose value d_{ij} is the assessment of the alternative a_i under the criteria c_j .

One of the most relevant steps in the resolution of a linguistic decision-making problem (see Fig. 1) consists of modelling the linguistic preferences provided by the experts. In this regard, there are several proposals introduced in the specialized literature, such as the 2-tuple linguistic representation model [8], which allows providing precise computations on linguistic expressions, the Comparative Linguistic Expressions (CLEs) [9], able to model the experts' hesitancy, or the ELICIT information, which hybridizes both proposals by introducing a representation scheme to model doubt without losing either interpretability or precision [7].

After choosing the desired preference structure, the experts' preferences are aggregated and then exploited in order to obtain a solution for the problem. Over the years, this scheme has been extended, which has given place to different MCGDM models [1]. Concretely, this proposal is based on the TODIM approach [3], which allows obtaining a ranking of the alternatives according to the experts' behavior when dealing with potential gains and losses as a result of their decisions [6].

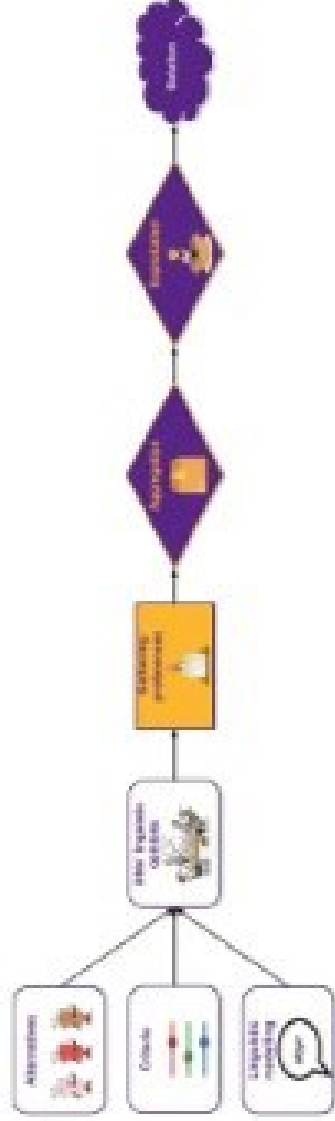


Fig. 1. Linguistic MCGDM resolution scheme.

2.2 2-Tuple Linguistic Model and ELICIT Information

The 2-tuple linguistic representation model [8] represents the linguistic information as a tuple (s_i, α) composed by a linguistic term $s_i \in S$, which belongs to a predefined linguistic term set $S = \{s_0, s_1, \dots, s_g\}$, and a numerical value $\alpha \in [-0.5, 0.5]$ so-called symbolic translation, which represents the displacement in a continuous linguistic expression domain of the s_i membership function.

Together with this representation model, Martínez et al. [8] also introduced a computational model which relies on the bijection $\Delta^{-1} : \bar{S} \rightarrow [0, g]$ defined by

$$\Delta_S^{-1}(s_i, \alpha) = i + \alpha, \quad \forall (s_i, \alpha) \in \bar{S},$$

where $\bar{S} = S \times [-0.5, 0.5]$ is the set of all 2-tuple linguistic values.

However, the 2-tuple linguistic modelling presents an important drawback, because it is not able to model the experts' hesitancy between several linguistic terms. To overcome this shortcoming, Rodríguez et al. [10] introduced the use of CLEs by using relations such as *between*, *at most* or *at least* that are more flexible and richer than single linguistic terms. Afterwards, Labella et al. [7] proposed the ELICIT information taking the advantages of the 2-tuple linguistic model and the CLEs, which it is not only able to model the experts' hesitation, but also allows carrying out precise computations and obtaining interpretable results. Furthermore, any ELICIT value is uniquely identified with a trapezoidal fuzzy number (TrFNs) [7]:

Remark 1. A TrFN is a function $T = T(a, b, c, d) : [0, 1] \rightarrow [0, 1]$ of the form

$$T(x) = \begin{cases} 0 & \text{if } 0 \leq x \leq a \\ \frac{x-a}{b-a} & \text{if } a < x < b \\ 1 & \text{if } b \leq x \leq c \\ \frac{d-x}{d-c} & \text{if } c < x < d \\ 0 & \text{if } d \leq x \leq 1 \end{cases} \quad \forall x \in [0, 1]$$

for certain $0 \leq a \leq b \leq c \leq d$. For the sake of clarity, the set of all TrFNs on the interval $[0, 1]$ will be denoted by

$$\mathcal{T} = \{T : [0, 1] \rightarrow [0, 1] : T \text{ is a TrFN}\}.$$

Formally, ELICIT information can be denoted by an expression $[\bar{s}_i, \bar{s}_j]_{\gamma_1, \gamma_2}$, where $\bar{s}_i, \bar{s}_j \in \bar{S}$, $i \leq j$ are two 2-tuple linguistic values and γ_1, γ_2 are two parameters which allow to unequivocally retrieve the TrFN representation of the ELICIT value [7]:

Proposition 1. Let $\bar{S}$ be the set of all possible ELICIT values. The mapping

$$\zeta^{-1} : \bar{S} \rightarrow \mathcal{T} \\ [\bar{s}_1, \bar{s}_2]_{\gamma_1, \gamma_2} \rightarrow T(a, b, c, d)$$

defined by:

$$\begin{aligned} a &= \gamma_1 + \max \left\{ \frac{\Delta_S^{-1}(\bar{s}_1) - \frac{1}{g}}{g}, 0 \right\}, & b &= \frac{\Delta_S^{-1}(\bar{s}_1)}{g}, \\ c &= \frac{\Delta_S^{-1}(\bar{s}_m)}{g}, & d &= \gamma_2 + \min \left\{ \frac{\Delta_S^{-1}(\bar{s}_m) + \frac{1}{g}}{g}, 1 \right\}, \end{aligned}$$

is a bijection.

ELICIT values can be ordered by translating the fuzzy envelopes of the ELICIT values, given by a TrFN, into a numerical value so-called magnitude [7], which is defined by:

$$Mag([s_i, s_j]_{\gamma_i, \gamma_j}) = Mag(T(a, b, c, d)) = \frac{a + 5b + 5c + d}{12} \in [0, 1].$$

To compare two ELICIT values it suffices to compute their respective magnitudes. According to Labella et al. [7] the larger the magnitude, the larger the ELICIT value. Finally, to measure the distance between two ELICIT values, they proposed the distance $\mu : \overline{S} \times \overline{S} \rightarrow [0, 1]$:

$$\begin{aligned} \mu([s_i^1, s_j^1]_{\gamma_1^1, \gamma_j^1}, [s_i^2, s_j^2]_{\gamma_1^2, \gamma_j^2}) &= \mu(T(a_1, b_1, c_1, d_1), T(a_2, b_2, c_2, d_2)) = \\ &= \frac{|a_1 - a_2| + |b_1 - b_2| + |c_1 - c_2| + |d_1 - d_2|}{4}, \end{aligned}$$

for any ELICIT values $[s_i^1, s_j^1]_{\gamma_1^1, \gamma_j^1}, [s_i^2, s_j^2]_{\gamma_1^2, \gamma_j^2} \in \overline{S}$.

3 ELICIT-TODIM

Here, it is considered a linguistic MCGDM problem in which a group of experts wants to select the best alternative according to different criteria, which have been rated by using ELICIT information.

Let us assume m experts, n alternatives, and r criteria. Therefore, a decision matrix for each expert is given by $D^k = (d_{ij}^k)_{n \times r}$, where d_{ij}^k represents by means of ELICIT information the rating of the alternative a_i under the criterion c_j provided by the expert e_k . In other words, d_{ij}^k is on the form $d_{ij}^k = [s_{ij}^{k1}, s_{ij}^{k2}]_{\gamma_{ij}^{k1}, \gamma_{ij}^{k2}}$ where s_{ij}^{k1} and s_{ij}^{k2} are 2-tuple linguistic terms. In addition, the importance of each criterion c_j according to expert e_k 's opinion is given by W_j^k , which is also an ELICIT value.

1. First, experts' preferences are aggregated by using an aggregation operator $F : \mathcal{T}^m \rightarrow \mathcal{T}$ [4].

$$\begin{aligned} d_{ij} &:= \zeta(F(\zeta^{-1}(d_{ij}^1), \zeta^{-1}(d_{ij}^2), \dots, \zeta^{-1}(d_{ij}^m))), \\ W_j &:= \zeta(F(\zeta^{-1}(W_j^1), \zeta^{-1}(W_j^2), \dots, \zeta^{-1}(W_j^m))). \end{aligned}$$

2. The value of the weight W_i for each criterion c_i is normalized according to its importance, which is computed by using the notion of magnitude of an ELICIT value:

$$w_j = \frac{Mag(W_j)}{\sum_{i=1}^r Mag(W_i)}$$

3. Compute the dominance of the alternative a_i over the alternative a_h , $\delta : A \times A \rightarrow \mathbb{R}$ given by $\delta(a_i, a_h) = \sum_{j=1}^r \phi_j(a_i, a_h)$, $\forall a_i, a_h \in A$, where $\phi_j :$

$A \times A \rightarrow \mathbb{R}$ is defined by

$$\phi_j(a_i, a_h) = \begin{cases} \sqrt{w_j \mu(d_{ij}, d_{hj})} & Mag(d_{ij}) > Mag(d_{hj}) \\ 0 & Mag(d_{ij}) = Mag(d_{hj}) \\ -\frac{1}{\theta} \sqrt{\frac{\nu(d_{ij}, d_{hj})}{w_j}} & Mag(d_{ij}) < Mag(d_{hj}) \end{cases}$$

4. Compute the partial dominance of each alternative

$$\xi_i = \frac{\sum_{h=1}^n \delta(a_i, a_h) - \min_{i=1}^n \sum_{h=1}^n \delta(a_i, a_h)}{\max_{i=1}^n \sum_{h=1}^n \delta(a_i, a_h) - \min_{i=1}^n \sum_{h=1}^n \delta(a_i, a_h)}$$

As it occurs in classical TODIM, the parameter $\theta > 0$ is used to measure the importance of the losses, which is amplified if $\theta < 1$ and reduced if $\theta > 1$. According to Prospect Theory [6], humans are usually more concerned about losses than about gains ($\theta < 1$). When choosing θ close to zero, the alternatives which produce small losses are the best ones. On the contrary, for high values of θ , TODIM provides solutions which prioritize benefits regardless of the losses.

4 Case Study

This section shows the performance of the proposal in the resolution of a linguistic MCGDM problem. A fast food franchise is considering building a new restaurant. This restaurant will require a large investment, thus an inappropriate location for the restaurant could lead to irreparable financial losses for the company. The company is evaluating 4 possible locations a_1 : New York, a_2 : Istanbul, a_3 : Barcelona and a_4 : Athens. Three experts are in charge to evaluate the possible locations according to four criteria, c_1 : climate business, c_2 : availability of raw materials, c_3 : investment cost and c_4 : labor characteristics. The experts provide their assessments through ELICIT information defined in the linguistic expression domain $S_1 = \{\text{Inadmissible (I), Very inadvisable (VI), Inadvisable (IN), Normal (N), Advisable (A), Very advisable (VA), Ideal (ID)}\}$. The criteria importance are also provided linguistically by using another linguistic expression domain: $S_2 = \{\text{Nothing important (NI), Very unimportant (VU), Unimportant (U) Fair (F), Important (IM), Very important (VIM), Extremely important (EI)}\}$. All these assessments are collected in the following decision matrices (see Table 1):

Table 1. Experts' preferences (bt stands for between).

Pref.	e_1	e_2	e_3	e_4
a_1	ID	A	bt IN and N	N
a_2	N	A	VA	VA
a_3	IN	N	A	VA
a_4	VI	IN	VA	VA
Weight	VTM	F	FI	F
a_1	VA	N	N	A
a_2	VI	VA	VA	ID
a_3	ID	N	ID	N
a_4	IN	IN	A	bt VI and IN
Weight	N	N	FI	N
a_1	N	bt VI and IN	VI	N
a_2	bt N and A	N	A	N
a_3	IN	A	A	A
a_4	N	A	N	A
Weight	I	V	VI	V

Firstly, the experts' preferences are transformed into TrFNs (see Table 2).

Table 2. Experts' preferences.

Pref.	e_1	e_2	e_3	e_4
a_1	$T(0.83, 1, 1)$	$T(0.5, 0.67, 0.83)$	$T(0.17, 0.33, 0.5, 0.67)$	$T(0.33, 0.5, 0.67)$
a_2	$T(0.33, 0.5, 0.67)$	$T(0.5, 0.67, 0.83)$	$T(0.67, 0.83, 1)$	$T(0.67, 0.83, 1)$
a_3	$T(0.17, 0.33, 0.5)$	$T(0.33, 0.5, 0.67)$	$T(0.5, 0.67, 0.83)$	$T(0.67, 0.83, 1)$
a_4	$T(0, 0.17, 0.33)$	$T(0.17, 0.33, 0.5)$	$T(0.67, 0.83, 1)$	$T(0.67, 0.83, 1)$
Weight	$T(0.67, 0.83, 1)$	$T(0.33, 0.5, 0.67)$	$T(0.83, 1, 1)$	$T(0.33, 0.5, 0.67)$
a_1	$T(0.67, 0.83, 1)$	$T(0.33, 0.5, 0.67)$	$T(0.33, 0.5, 0.67)$	$T(0.5, 0.67, 0.83)$
a_2	$T(0, 0.17, 0.33)$	$T(0.67, 0.83, 1)$	$T(0.67, 0.83, 1)$	$T(0.83, 1, 1)$
a_3	$T(0.83, 1, 1)$	$T(0.33, 0.5, 0.67)$	$T(0.83, 1, 1)$	$T(0.33, 0.5, 0.67)$
a_4	$T(0.17, 0.33, 0.5)$	$T(0.17, 0.33, 0.5)$	$T(0.5, 0.67, 0.83)$	$T(0, 0.17, 0.33, 0.5)$
Weight	$T(0.33, 0.5, 0.67)$	$T(0.33, 0.5, 0.67)$	$T(0.83, 1, 1)$	$T(0.33, 0.5, 0.67)$
a_1	$T(0.33, 0.5, 0.67)$	$T(0, 0.17, 0.33, 0.5)$	$T(0, 0.17, 0.33)$	$T(0.33, 0.5, 0.67)$
a_2	$T(0.3, 0.5, 0.67, 0.83)$	$T(0.33, 0.5, 0.67)$	$T(0.5, 0.67, 0.83)$	$T(0.33, 0.5, 0.67)$
a_3	$T(0.17, 0.33, 0.5)$	$T(0.5, 0.67, 0.83)$	$T(0.5, 0.67, 0.83)$	$T(0.5, 0.67, 0.83)$
a_4	$T(0.33, 0.5, 0.67)$	$T(0.5, 0.67, 0.83)$	$T(0.33, 0.5, 0.67)$	$T(0.5, 0.67, 0.83)$
Weight	$T(0.5, 0.67, 0.83)$	$T(0.17, 0.33, 0.5)$	$T(0.67, 0.83, 1)$	$T(0.17, 0.33, 0.5)$

Then, the individual preferences and weights are aggregated by using the fuzzy arithmetic mean operator to obtain the collective opinion (see Table 3).

Table 3. Collective opinion.

Col.	e_1	e_2	e_3	e_4
a_1	$T(0.61, 0.78, 0.78, 0.89)$	$T(0.28, 0.45, 0.5, 0.67)$	$T(0.17, 0.33, 0.33, 0.56)$	$T(0.39, 0.56, 0.56, 0.72)$
a_2	$T(0.21, 0.39, 0.45, 0.61)$	$T(0.5, 0.67, 0.67, 0.83)$	$T(0.61, 0.78, 0.78, 0.94)$	$T(0.61, 0.78, 0.78, 0.89)$
a_3	$T(0.39, 0.55, 0.55, 0.67)$	$T(0.39, 0.56, 0.56, 0.72)$	$T(0.61, 0.78, 0.78, 0.94)$	$T(0.5, 0.67, 0.67, 0.83)$
a_4	$T(0.17, 0.33, 0.33, 0.5)$	$T(0.28, 0.44, 0.44, 0.61)$	$T(0.5, 0.67, 0.67, 0.83)$	$T(0.45, 0.61, 0.61, 0.78)$
Weight	0.27	0.18	0.38	0.17

Afterwards, the collective weights are normalized according to Eq. 2.: $w_1 = 0.27$, $w_2 = 0.18$, $w_3 = 0.38$ and $w_4 = 0.17$. Finally, the partial dominance degree is computed for each alternative (with $\theta = 0.5$) to obtain the ranking for the alternatives: $\xi_1=0$, $\xi_2=1$, $\xi_3=0.84$ and $\xi_4=0.04$. Therefore, the final ranking is $\xi_2 \succ \xi_3 \succ \xi_4 \succ \xi_1$ and, consequently, the best location for the new restaurant is x_2 : Istanbul.

5 Conclusions

The resolution of MCGDM problems involves several aspects such as the management of uncertainty, the experts' hesitancy between ratings, and their behavior when facing losses and gains, which may affect the final solution of the problem.

This contribution has introduced an ELICIT-TODIM method for MCGDM problems, a novel approach able to model uncertainty and hesitancy in experts' preferences by means of ELICIT information. This proposal also considers that human stake-holders act in a more conservative way under risk situations in which huge losses are involved. Afterwards, the application of the proposal is shown in an illustrative example.

As future research, it would be of interest to analyze the use of nonlinear scales [2] in decision-makers' opinions and deal with the interpretation of extreme values in Prospect Theory. In addition, other studies should be devoted to apply this proposal to solve decision problems which could involve numerous stakeholders. Furthermore, we will consider to include a consensus mechanism in the aggregation phase to obtain an agreed solution to the MCGDM problem.

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