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Using the TODIM-FSE method as a decision-making support methodology for oil spill response*

Aderson Campos Passos †[a]; Marcelo Goulart Teixeira[b]; Kátia Cristina Garcia[c]; Anelise Menezes Cardoso[c]; Luiz Flávio Autran Monteiro Gomes[d]

[a]Department of Computer Engineering – Military Institute of Engineering (IME, Rio de Janeiro, Brazil) Praça General Tibúrcio, 80, Praia Vermelha, Rio de Janeiro, RJ, Brazil, CEP 22290-270. E-mail: aderson@ime.eb.br

[b]Department of Computer Science – Federal University of Rio de Janeiro (UFRJ, Rio de Janeiro, Brazil). Caixa Postal 68.530, CEP 21941-590, Rio de Janeiro - RJ – Brazil. E-mail: marcellogt@dcc.ufrj.br

[c]Interdisciplinary Environmental Laboratory (LIMA) – Energetic Planning Program, (COPPE), Federal University of Rio de Janeiro, Centro de Tecnologia Bloco I 2000 sala 208, Cidade Universitária, Rio de Janeiro, RJ, Brazil, CEP: 21949-900. E-mail: garciak@lima.coppe.ufrj.br, anecardoso@lima.coppe.ufrj.br

[d]Ibmec/RJ, Av. Presidente Wilson, 118, 11th floor, Rio de Janeiro, RJ, Brazil, CEP: 20030-020. E-mail: autran@ibmecrj.br

Abstract. *This paper introduces a multi-criteria method for solving classification problems, called TODIM-FSE. This name was chosen because its structure merges characteristics from two different methods: TODIM and FSE. In order to demonstrate TODIM-FSE, a model was constructed aimed at helping potential users to decide upon suitable contingency plans for oil spill situations. The model is envisaged as embedded within SISNOLEO (a Portuguese acronym for An Information System for Oil Spill Planning) which is subsequently described in the article. The fundamentals of this method, several key references and a case study are also provided.*

Keywords: Multiple criteria analysis; TODIM-FSE; oil spill response; SISNOLEO; environmental damage

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† Corresponding author: Tel: 00 55 21 2546 – 7249, FAX: 00 55 21 2546 – 7092

1. Introduction

Fuzzy Synthetic Evaluation (henceforth FSE) was first launched as an environmental index to evaluate the water quality in reservoirs [1]. In the same article, both the need to take into account several conflicting elements simultaneously, as well as the inaccurate judgments of these elements, were clearly underlined. This is why concepts of multi-criteria decision analysis, together with fuzzy logic were brought in.

Several papers have been published using the same methodology. Most of these have adjusted environmental modeling in order to create alternative evaluation indices [1; 2; 3]. However, articles using the FSE in well-defined decision problems [4; 5] may also be found. For this reason, we consider FSE as a multi-criteria decision method.

Another multi-criteria method already known in the scientific literature is TODIM [6, 7, 8, 9, 10]. Its main feature is to take into account the risk embedded in the decision makers´ judgments, by adapting in its aggregation function the value function of Kahneman and Tversky´s Prospect Theory [11]. However, differently from FSE, TODIM is a method that analyzes a set of alternatives (or courses of action) and provides their order of preference.

The main objective of the present text is to introduce an innovative method for solving multi-criteria classification problems (Pβ) that merges characteristics from both methods (TODIM and FSE), and also demonstrate its characteristics, as well as describe the procedures aimed at obtaining final results. In order to illustrate these proposals for using this method (henceforth TODIM-FSE), a model is provided which has been applied in a case study. The aim had been to establish the most suitable contingency plan for each oil spill occurrence. A further research objective is to describe the context in which the model is applied. This is, namely, the development of SISNOLEO (an acronym in Portuguese for an Information System for Oil Spill Planning and Response). This paper will also provide a general description of the aforementioned system, in which the model was seen to be embedded.

2. The TODIM-FSE method: a Pβ approach

The TODIM-FSE method assembles characteristics from two different multi-criteria methods. The fundamental idea of the FSE aggregation procedure is to derive a weighted sum of the membership values for each category. These weights relate to the relative importance of criteria. This should be carried out successively until a final vector is obtained. The components of this vector are the membership values for each alternative related to the defined categories.

To illustrate the general algebra for FSE, the hierarchical structure of the case study (figure 5) will be used as an example. This case will be described in detail in section 3. The SC_1, SC_2 and SC_3 sub-criteria are subordinated to C_1 criteria. The judgments for each sub-criterion will be transformed into the following vectors:

$$V_{SC_1} = [\mu_{small} \quad \mu_{medium} \quad \mu_{great}]$$

$$V_{SC_2} = [\mu_{high} \quad \mu_{medium} \quad \mu_{low}]$$

$$V_{SC_3} = [\mu_{short} \quad \mu_{medium} \quad \mu_{long}]$$

For this group of sub-criteria a vector of weights was established:

$$W_1 = [W_{SC_1} \quad W_{SC_2} \quad W_{SC_3}]$$

In order to group these values, vector B_{C_1} must be obtained, resulting from the following matrix operation:

$B_{C_1} = W_1 \times A_{C_1}$, where A_{C_1} is a matrix obtained after the merge of the vectors V_{SC_1}, V_{SC_2}, V_{SC_3}. Hence,

$$B_{C_1} = \begin{bmatrix} W_{SC_1} & W_{SC_2} & W_{SC_3} \end{bmatrix} \times \begin{bmatrix} \mu_{small} & \mu_{medium} & \mu_{great} \\ \mu_{high} & \mu_{medium} & \mu_{low} \\ \mu_{short} & \mu_{medium} & \mu_{long} \end{bmatrix}$$

$$B_{C_1} = \begin{bmatrix} \mu^{C_1}_{national} & \mu^{C_1}_{regional} & \mu^{C_1}_{local} \end{bmatrix}$$

This procedure should be carried out for each criterion, and the final aggregation ought to occur as described below:

$$\text{Final vector} = \begin{bmatrix} W_{C_1} & W_{C_2} & W_{C_3} & W_{C_4} & W_{C_5} & W_{C_6} \end{bmatrix} \times \begin{bmatrix} \mu^{C_1}_{national} & \mu^{C_1}_{regional} & \mu^{C_1}_{local} \\ \mu^{C_2}_{national} & \mu^{C_2}_{regional} & \mu^{C_2}_{local} \\ \mu^{C_3}_{national} & \mu^{C_3}_{regional} & \mu^{C_3}_{local} \\ \mu^{C_4}_{national} & \mu^{C_4}_{regional} & \mu^{C_4}_{local} \\ \mu^{C_5}_{national} & \mu^{C_5}_{regional} & \mu^{C_5}_{local} \\ \mu^{C_6}_{national} & \mu^{C_6}_{regional} & \mu^{C_6}_{local} \end{bmatrix}$$

$$\text{Final vector} = \begin{bmatrix} \mu_{national} & \mu_{regional} & \mu_{local} \end{bmatrix}$$

To obtain the final classification, the choice of a category with a higher μ value will be needed.

The second method, the TODIM (an acronym in Portuguese for Interactive and Multi-criteria Decision Making) is a multi-criteria method that has as its main feature the use of the paradigm of Prospect Theory by Kahneman and Tversky [11]. One of the characteristics of the Prospect Theory, whose authors were awarded the Nobel Prize in Economics for this work in 2002, is the analysis of human behavior in the face of risk. The method uses such characteristic adapting its aggregation function to incorporate this aspect of human behavior. Thus, the TODIM becomes an appropriate method to tackle problems with risk decisions. As a result, it provides the ordering of alternatives and, therefore, is characterized as a Pγ method.

The proposed method uses the initial stages of the FSE and the final stages of TODIM, adjusting it so that it is possible to obtain a result that represents the sorting of alternatives. Goodwin and Wright [12] suggested a set of steps to facilitate the understanding and application of SMART, a multi-criteria method proposed by Edwards [13]. A similar idea is used to define the decision making process by applying the TODIM-FSE. The following sections will describe each of the steps used for this method:

Step 1 – Definition of decision makers and decision analysts.

Step 2 – Detailed analysis of the decision problem and problem structuring.

Step 3 – Definition of the relevant criteria for the problem.

Step 4 – Definition of the number of classification categories, the fuzzy sets associated with each criterion, and fuzzification procedures.

Step 5 – Establishment of the relative importance of the selected criteria.

Step 6 – Classification of each alternative in one of the proposed categories defined in step 4.

Step 7 – Sensitivity analysis.

2.1. Definition of decision makers and decision analysts (step 1)

The decision makers are the people who will make judgments about the decision problem. The decision analysts are the specialists in decision support processes and methods. It may also be considered the possibility of aggregating judgments from experts in specific knowledge related to the problem. In this case, these experts will be regarded as decision makers.

2.2. Decision problem analysis and structuring (step 2)

The decision problem must be analyzed to verify the possibility and necessity of using a multi-criteria decision support method. Sometimes the problem is simple and does not require its use. If the decision problem is a classification of alternatives, then the TODIM-FSE method can be used. The relevance of problem structuring is widely recognized. A comprehensive set of references about the subject can be found in [14].

2.3. Definition of the relevant criteria for the problem (step 3)

This step involves defining what should be taken into consideration to make the decision. One way of defining these criteria is through a brainstorming session with people interested in the problem. After defining a large set of possible criteria it is necessary to select some of them. A set of criteria will need to be defined in order to match the qualities of completeness, nonredundancy, operationality, minimum size and decomposability proposed by Keeney and Raiffa [15].

2.4. Definition of categories and fuzzification (step 4)

In this methodological step, the decision makers´ preferences are used to define both the categories themselves and the boundaries between each of the categories. In this case, the first feature to be focused upon is the number *k* of categories to be classified. The numeric value of *k* will define the quantity of linguistic variables used in the evaluation of alternatives for each criterion.

Thus, we will let A be the set of criteria used to classify the alternatives; *n* will be defined as the cardinality of A, and *c* as a generic criterion of A.

The features of *c* will be evaluated by a specialist who, together with a decision analyst, will transform their knowledge of the problem into fuzzy variables. The *k* linguistic variables, used to classify *c*, will be established by specialist interviews and/or statistical data. Thus, suppose that *crit i* can be classified with $k = 3$. Using, as an example, the SC_2 sub-criterion from the case study (i.e., the type of oil in terms of its persistence - ^{o}API), three fuzzy variables were defined, namely, high, medium and low. The model details will be explained later in the present paper. For the moment, suffice to say that the definition of these linguistic variables may be achieved using several kinds of fuzzy sets. Figure 1 illustrates a composition of sigmoidal functions, constructed using information specialists from the field of petroleum studies.

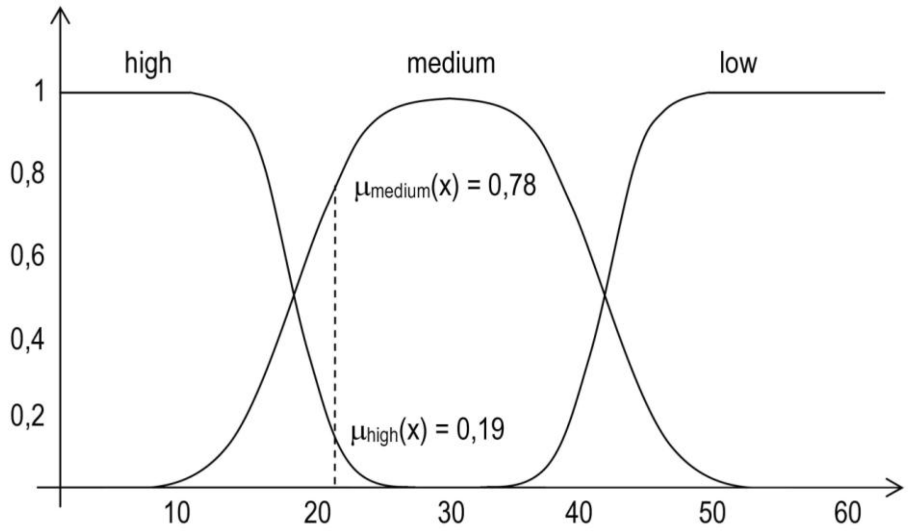

Figure 1: Fuzzy sets representing the specialist's judgments about SC_2 sub-criteria (type of oil in terms of its persistence - °API)

To define the level of contingency action for oil spill response, a hypothetical value of 21 °API for SC_2 will be used. Subsequently, a vector of *k* elements will be defined which denote the membership degrees for this value in each fuzzy set. The resulting vector is:

[$\mu_{high}(x) = 0.19$ $\mu_{medium}(x) = 0.78$ $\mu_{low}(x) = 0$]

This approach may be used for both quantitative (similar to SC_2), and qualitative criteria. The sub-criteria Environmental Sensitivity (SC_6) in this case study, was evaluated using a cardinal scale with values ranging between 0 (zero) and 10 (ten). Another possibility for this modeling is to evaluate the alternative using a verbal scale. In this case, when the evaluation is *low*, the resulting vector becomes:

[$\mu_{low}(x) = 1$ $\mu_{medium}(x) = 0$ $\mu_{high}(x) = 0$]

If the decider evaluation is a judgment between *low* and *medium*, for example, the resulting vector is:

[μ_{low} (x) = 0.5 μ_{medium} (x) = 0.5 μ_{high} (x) = 0]

In addition, intermediate judgments may assume infinite combinations. However, there is a well-known human restriction in issuing qualitative judgments, described in Miller´s [16] classical article. For this reason, no more than 9 (nine) different levels in the verbal scale (associated with an equal number of vectors) are expected, in the evaluation of each qualitative criteria.

There is an important observation related to this method in terms of the definition of fuzzy sets. The decision analyst must make it clear to the decision maker that each of these sets will be associated with a classification category. For the previous example, when setting the value 21 ° API for SC_2 sub-criterion (Figure 1) the following fuzzification is obtained: [μ_{high}(x) = 0.19 μ_{medium}(x) = 0.78 μ_{low}(x) = 0]. This means that this sub-criterion contributes to 0.19 for the alternative to qualify under category 1, 0.78 for the alternative to qualify under Category 2 and 0 for the alternative to qualify under Category 3 (in a 0-1scale). This is a fundamental concept to understanding the final result. The mathematical details will be presented in the case study.

2.5. Definition of the relative importance between criteria (step 5)

In a seminal paper on FSE [1], the pairwise comparison matrices from Saaty´s Analytic Hierarchy Process (AHP) are the reference for defining the relative weights between criteria. His fundamental scale [17] has also been used to complete these matrices, as demonstrated in Table 1.

However, a variation of this procedure has been introduced in the present research, by which the inconsistency related to each pairwise comparison matrices may be eliminated. This is the same as that adopted in the TODIM method [6; 7; 8; 9; 10].

NUMERICAL SCALE	VERBAL SCALE
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very Strong importance
9	Extreme importance
2,4,6,8	Intermediate values

Table 1: Saaty's fundamental scale

Inconsistency elimination will be accomplished utilizing the following steps:

a. Deriving the priority vector *p* from the pairwise comparison matrix, as proposed by Saaty [17], where

$p = [\ a_1 \ \ a_2 \ \ \ldots \ \ a_n\ ]$

b. From the weights obtained (as components of the priority vector *p*), an alternative matrix is built, as shown in (1). This matrix has a consistency index equal to zero, because its elements are determined by the ratio between the weights of criteria associated with that element. Therefore, if b_{ij} is an element of this matrix, then its value will be a_i / a_j, where a_i and a_j are, respectively, the weights of criteria i and j, as seen below:

$$\begin{bmatrix} \frac{a_1}{a_1} & \frac{a_1}{a_2} \ldots\ldots\ldots\ \ldots\ldots & \frac{a_1}{a_n} \\ \frac{a_2}{a_1} & \frac{a_2}{a_2} \ldots\ldots\ldots\ \ldots\ldots\ldots & \ldots \\ \ldots\ldots\ldots & \ldots\ldots\ldots\ \ldots\ldots\ldots & \ldots\ldots \\ \frac{a_n}{a_1} & \frac{a_n}{a_2} \ldots\ldots\ldots\ \ldots\ldots\ . & \frac{a_n}{a_n} \end{bmatrix} \qquad (1)$$

c. This newly generated matrix will be used in the modeling process. Each element of the priority vector W will be calculated as the direct row sum average. Subsequently, these values are normalized by dividing the elements by the sum of its components. This procedure, which was proposed by Saaty [17], replaces the calculation of the eigenvector of the matrix of paired comparisons. This is done to avoid the problems mentioned by Bana e Costa and Vansnick [18] in the calculation of the eigenvector. Hence,

$$W = (w_1 \quad w_2 \quad \ldots \quad w_n) \qquad \text{where} \qquad \sum_{i=1}^{n} w_i = 1$$

2.6. Classification of each alternative in one of the proposed categories (step 6)

To perform the classification of each alternative the aggregation function proposed in the TODIM method is used. As already mentioned, it takes into account the risk in decision making by incorporating the value function of Prospect Theory. The original result from TODIM method is the ranking of alternatives.

The inputs of TODIM method are the relative weights of criteria and the judgments assigned to each alternative from the perspective of each criterion. In the method presented in this paper the TODIM original aggregation function receives as alternatives, the k categories defined in step 4. The membership values obtained in each of the k fuzzy sets, in a particular criterion, indicate that the contribution of that criterion to that alternative belongs to a particular category. The matrix of membership values of categories against criteria, table 2, contains fuzzifying judgments of each criterion.

Criteria	Categories					
	Cat_1	**Cat_2**	**…**	**Cat_i**	**…**	**Cat_k**
C_1	μ_{11}	μ_{12}	…	μ_{1i}	…	μ_{1k}
C_2	μ_{21}	μ_{22}	…	μ_{2i}	…	μ_{2k}
…	…	…	…	…	…	…
C_j	μ_{j1}	μ_{j2}	…	μ_{ji}	…	μ_{jk}
…	…	…	…	…	…	…
C_n	μ_{n1}	μ_{n2}	…	μ_{ni}	…	μ_{nk}

Table 2: Matrix of membership values of categories against criteria

The table 2 will store the values obtained in step 4. With these values the partial matrices of dominance ($\Phi_c(cat_i,cat_j)$) are constructed, one for each criterion c. With these matrices the final matrix of dominance $\delta(cat_i, cat_j)$, subject of the following equation, will be calculated.

$$\delta(cat_i, cat_j) = \sum_{c=1}^{n} \Phi_c(cat_i, cat_j) \qquad \forall (i,j)$$

with:

$$\Phi_c(cat_i, cat_j) = \begin{cases} \sqrt{\dfrac{w_{rc}(\mu_{ic} - \mu_{jc})}{\sum_{c=1}^{n} w_{rc}}} & if\ \mu_{ic} - \mu_{jc} > 0, \\ 0 & if\ \mu_{ic} - \mu_{jc} = 0, \\ -\dfrac{1}{\theta}\sqrt{\dfrac{(\sum_{c=1}^{n} w_{rc})(\mu_{jc} - \mu_{ic})}{w_{rc}}} & if\ \mu_{ic} - \mu_{jc} < 0 \end{cases}$$

The value w_{rc} represents the weight of criterion c divided by the weight of the reference criterion r. The latter is the criterion that will hold the greater weight. The value θ is the attenuation factor of the losses. Different choices of θ lead to different shapes of the prospect value function in the negative quadrant (Figure 2).

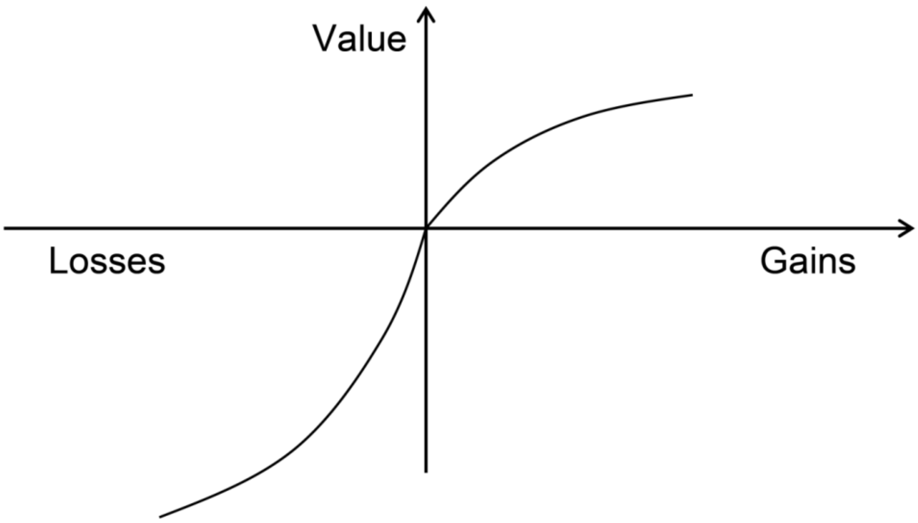

Figure 2: Prospect Theory’s value function

The final classification of the alternative will be obtained with the analysis of the vector X (pronounced as “xi”). Each of the k components of this vector represents the final membership value that the alternative has in each category. The component with the highest value indicates the category selected for the classification. Each component ξ_i is calculated using the following equation

$$\xi_i = \frac{\sum_{j=1}^{k} \delta\left(cat_i, cat_j\right) - min \sum_{j=1}^{k} \delta\left(cat_i, cat_j\right)}{máx \sum_{j=1}^{k} \delta\left(cat_i, cat_j\right) - min \sum_{j=1}^{k} \delta\left(cat_i, cat_j\right)}$$

2.7. Sensitivity Analysis (step 7)

This is an important step in the model construction. Here, judgments with doubtful values may be repeated, in order to verify whether the variation affects the overall classification. This is followed by interviews with specialists, who are responsible for the definition of fuzzy sets, as well as the weighting for criteria and sub-criteria. The coherence between the real problem and the classification obtained in the model may then be verified. If this is not achieved then a further analysis of the model will be necessary. In this way it may be possible to establish new weights for both the criteria and the new fuzzy sets.

3. Application context: the Brazilian oil spill information system (SISNOLEO)

The Brazilian contingency structure of response for oil spill is still under development. The Brazilian National Contingency Plan, for example, is being evaluated by national authorities and it is still awaiting government approval in a legal procedure which began in 2002.

One positive element in terms of the draft of the Brazilian National Contingency Plan is the SISNOLEO. This has been defined as an information system with real time access capable of collecting, analyzing, providing and disseminating all relevant information used in an efficient response action. As the draft of the Brazilian Plan fails to include details of the structure of the system, Cardoso et al [19], Cardoso [20] and SISNOLEO/COPPE/UFRJ [21] proposed structural details, based on the international experience of Australia, Canada, USA and United Kingdom, as well as on the specific characteristics of Brazilian oil and gas exploration and production (E&P) activities.

According to their proposal, the system should be able to permit real time access and response to any oil spill accident reported in Brazilian waters, by identifying their geographic location and by the characteristics of the sites in question. To achieve this, the system has been devised in two different modules. The first focuses on the information needed to plan the different response levels to oil spills; the second focuses on the response actions themselves, as shown in Figure 3. Thus, the system should be capable of collecting and disseminating all relevant information needed to guarantee an efficient accident response. This will include information regarding airports, railroads, ports, civil defense, hospitals, and other important data, such as that relating to hydrographic basins, satellite images, meteorological and oceanographic data, cartographic data and data on protected sites. All this data will be housed within a geo-referenced base, in order to achieve subsequent mapping elaboration, superposition and analyses.

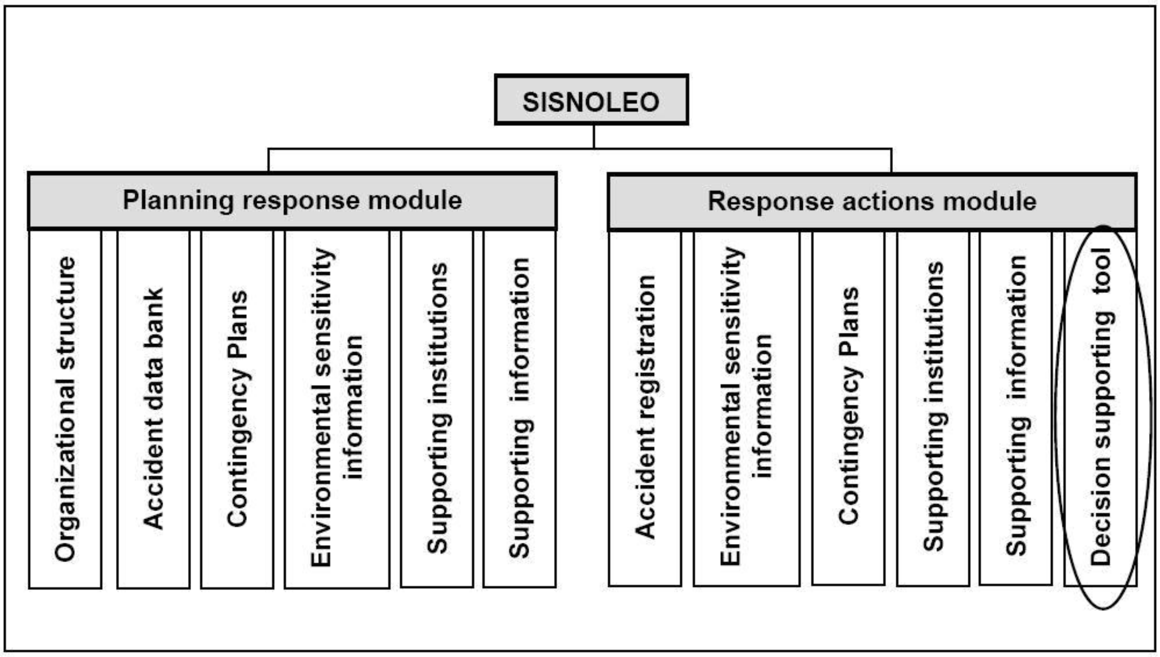

Figure 3: Modules of SISNOLEO (adapted from [20]).

It may be observed that certain parties may participate not only in the response module, but also in the planning module. This underlines the fact that information acquired in past response actions may be used to define new planning strategies, a characteristic of continuous improvement and retro-feeding processes.

This paper proposes that a fuzzy decision support tool in the Response Actions Module of SISNOLEO, specifically in the “Decision supporting tool” group of information, be included, using a model structured on TODIM-FSE. This tool aims to aid the decision-making regarding the evaluation of the accident, which will involve both the evaluation of the severity of the oil spill, as well as the selection of the appropriate level of response (Figure 4). It is important to remember that this is an auxiliary tool which takes into account the most relevant criteria to be considered at the moment of an accident, according to the opinion and experience of an expert group of the environmental, risk analysis, contingency response and legal areas, both of government and private sector, consulted to aid the development of the proposed decision-tool. Nowadays, in Brazil, the final decision is made by a Sectorial Coordinator, who may also take into consideration further factors which have not been included in the tool, but which may be important in certain specific contexts.

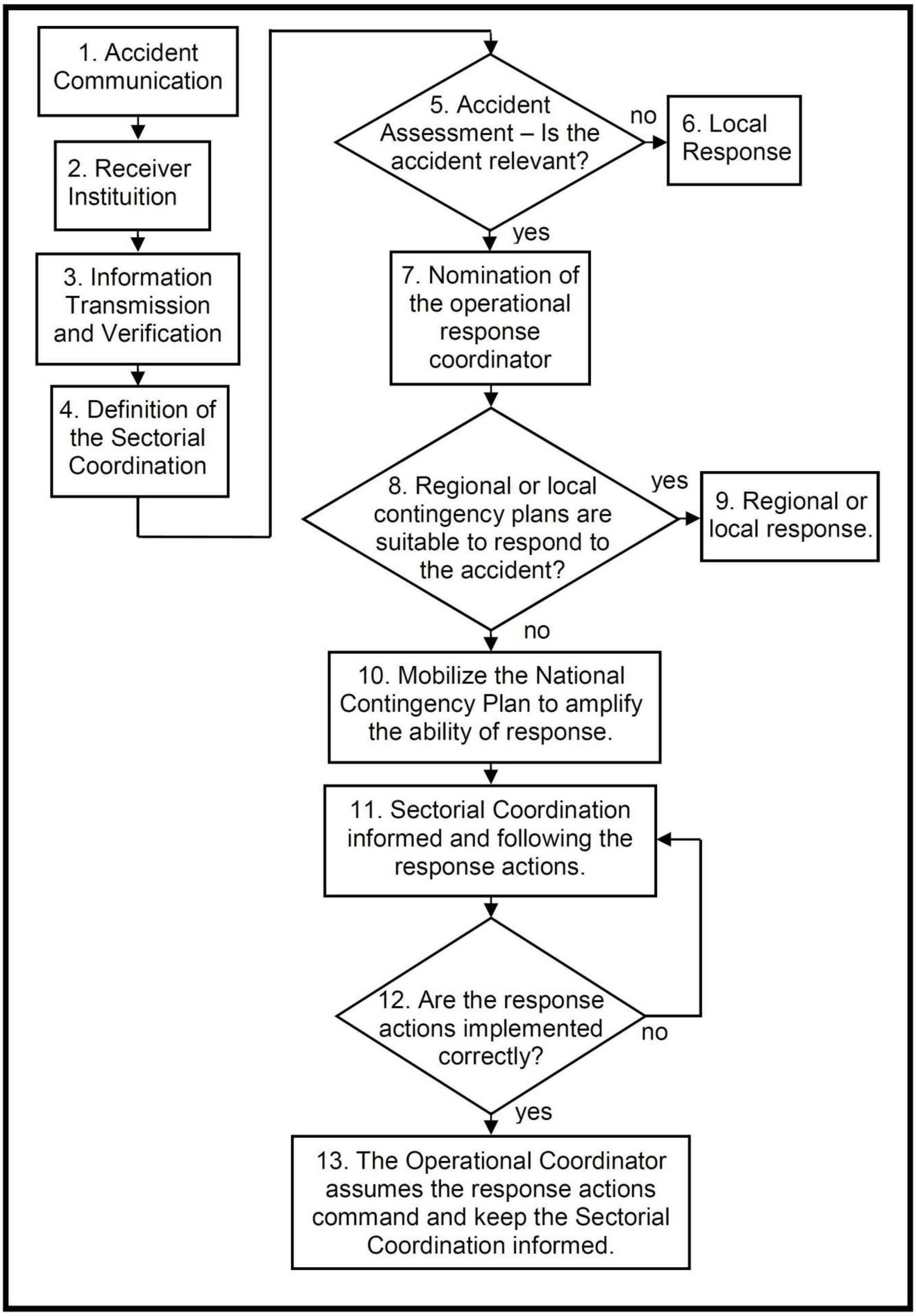

Figure 4: Decision chart regarding the level of response to oil spills [20]

3.1. Fuzzy decision-support model for oil spill response and case study

The steps proposed in Section 2 were followed, in order to develop the fuzzy decision-support model for oil spill response using the TODIM-FSE, as well as to establish the fuzzy membership functions of the input criterion for the system itself.

The fuzzy model is designed to receive few input data and provide a quick decision support. Considering the Brazilian context, several criteria were selected. According to the location where oil spill occurs, the classification will be different.

Step 1: it was believed essential to enlist the participation of a group made up of experts in risk and accident analyses, in the oil sector and environmental fields. In this way the inclusion of relevant data and perceptions of key stakeholders usually involved in spill responses, would well be guaranteed.

Step 2: the problem was approached by experts with the decision analyst. The decision problem was identified as a classification of alternatives problem. The TODIM-FSE method was used.

Step 3: by carrying out the series of steps described above, it was possible to obtain six well-define groups of criteria to aid an analysis. These are demonstrated in table 3. The criteria were grouped according to their similarities and levels of interaction.

Criteria	Sub-criteria
C_1: Severity of accident	SC_1: Volume spilled (liters) SC_2: Type of oil in terms of its persistent (^oAPI) SC_3: Spill duration (hours)
C_2: Chance of oil of reaching the coast	SC_4: Distance from the spill to the coast (Km) SC_5: Shift and spread of the spill (yes/no)
C_3: Environmental sensitivity of the affected area	SC_6: Environmental sensitivity (grade) SC_7: Presence of extreme sensitive ecosystems (yes/no)
C_4: Socioeconomic sensitivity	SC_8: Tourism activities (grade) SC_9: Fishing activities (grade)
C_5: Response capacity	SC_{10}: Adequacy of the response equipment to the spill (grade) SC_{11}: Adequacy of the response team to the spill (grade)
C_6: History of previous spills in the affected area	SC_{12}: Previous exposure to accidents as oil spills (grade) SC_{13}: Level of environmental degradation of the area (grade)

Table 3: Criteria and sub-criteria of the fuzzy-system

This fuzzy model was developed as an hierarchical structure (Figure 5) composed of: input sub criterion (SC_i, i = 1,…,13); criterion (C_i, i = 1,…,6); and a final result that indicates the level of response considered more appropriate according to the characteristics of the spill.

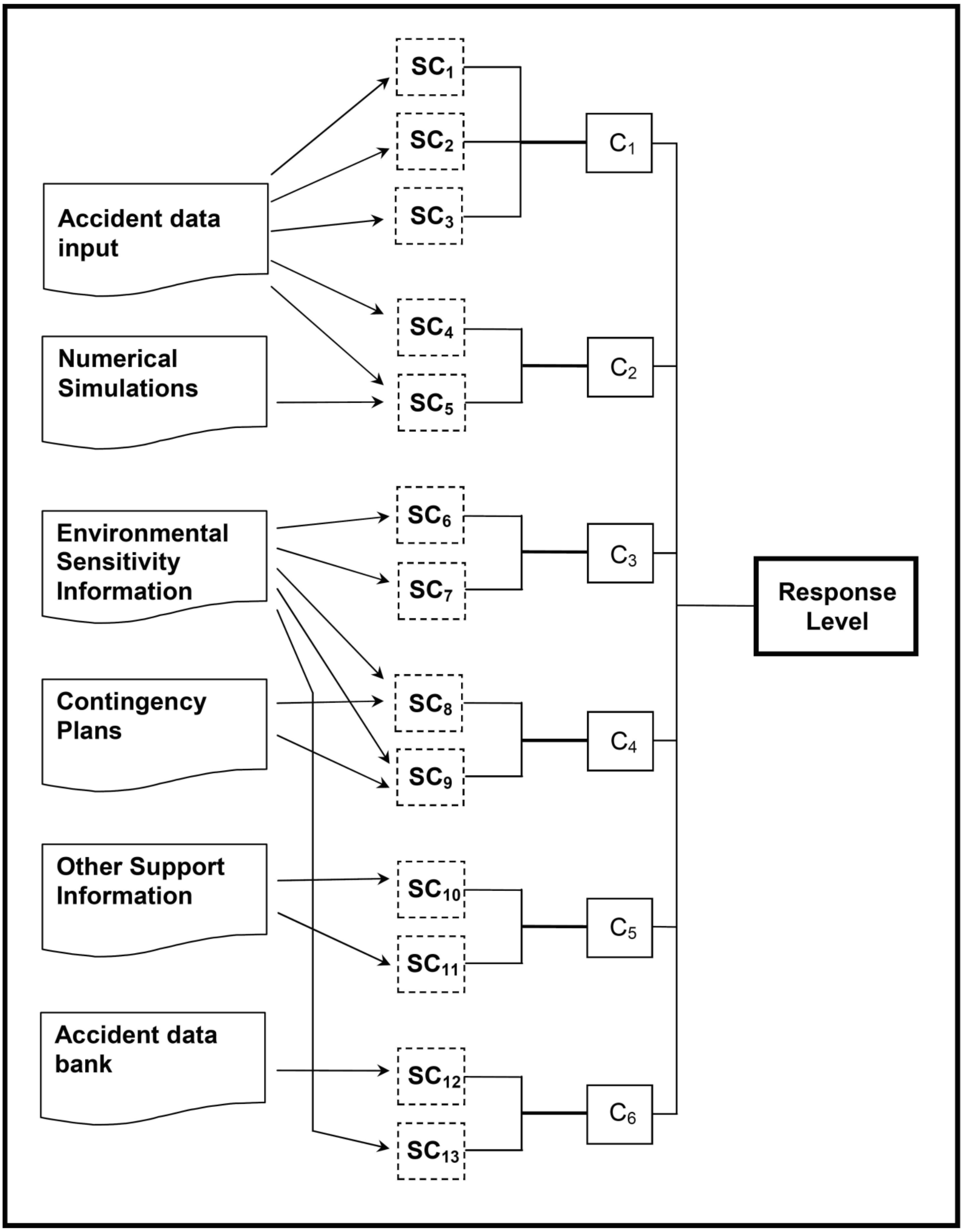

Figure 5: Hierarchic structure for the case study

Step 4: the objective of this decision problem is to frame a contingency action for each of the following response levels categories, and to help agents to take positive decisions when oil spills occur:

- ***Local level:*** demands the trigger of an Individual Emergency Plan (IEP), usually associated with small scale oil spills, generally near to the operator facilities and caused by failures in the activities of the installations. The IEP is a formal document which registers a set of response procedures in case an accident occurs on its installations.
- ***Regional level*:** demands the trigger of an Area Plan (AP), usually associated with intermediate scale oil spills, generally near to operator facilities and its surroundings and caused by failures in their own activities. To tackle oil spills of this dimension additional resources from other companies or from governmental agents are required. The AP is a document which registers the response procedures to integrate several IEPs from a specific geographical area.
- ***National level*:** demands the trigger of a National Contingency Plan (NPC), usually associated with large scale oil spills, with greater probability of damage and impact on the environment. The NPC establishes the organizational structure aimed at coordinating and extending the ability to respond at a national level to accidents of greater magnitude.

Figure 5 provides a chart of the proposed fuzzy model, highlighting the sources of information in the SISNOLEO response module. The final step defines fuzzy functions related to input criteria. Sigmoidal functions were chosen, and expressed by:

$$f(x) = \frac{1}{1 + e^{-ax+b}}$$

where *a* and *b* are chosen to best fit the curve to the information provided by the experts. A series of curves are represented in Figure 6 for the criterion SC_1, SC_2, SC_3, SC_4, SC_6, SC_8, SC_9, SC_{10}, SC_{11}, SC_{12}, SC_{13}.

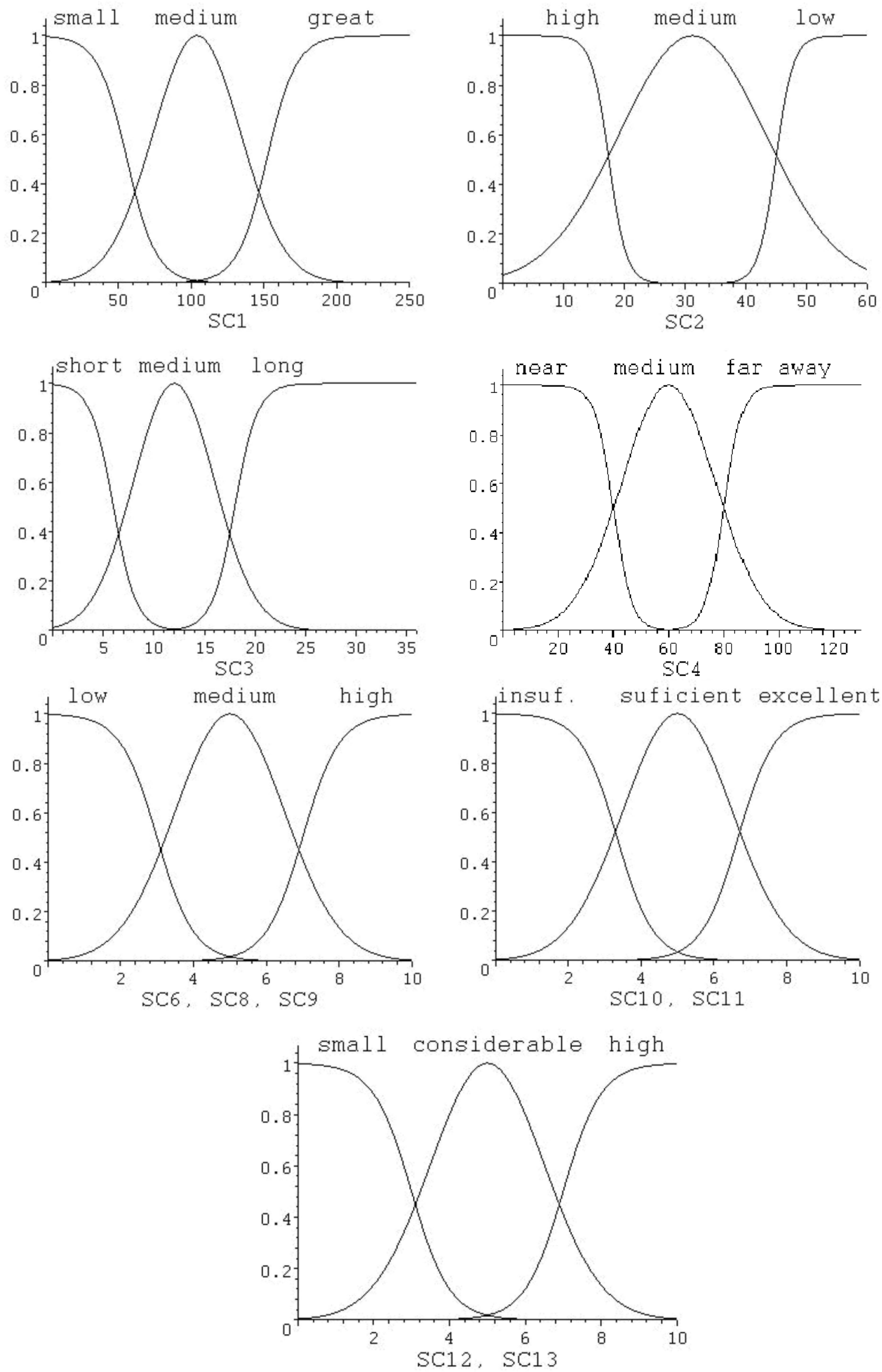

Figure 6: Fuzzy membership functions for the input criterion: (a) SC_1; (b) SC_2; (c) SC_3; (d) SC_4; (e) SC_6, SC_8 and SC_9; (f) SC_{10} and SC_{11}; (g) SC_{12} and SC_{13}.

In addition, the criteria SC_5 and SC_7 possess certain particularities. The sub-criterion SC_5 is considered a crisp sub-criterion. Thus, when the *shift and spread of the spill* are considered favorable, the pertinence degrees of the three hypothetical membership functions are [0, 0, 1]. Otherwise, where this proves unfavorable, the degrees of pertinence are [1, 0, 0]. The same logic is also applied to the sub-criteria SC_7.

Step 5: to define the relative importance between the criteria we used the procedures suggested in section 2. The experts were interviewed and provided the following weights for the sub-criteria and criteria presented in Tables 4 and 5, respectively.

Weights of sub-criteria					
Criterion 1	**Criterion 2**	**Criterion 3**	**Criterion 4**	**Criterion 5**	**Criterion 6**
SC_1 - 0.375	SC_4 - 0.5	SC_6 - 0.5	SC_8 - 0.5	SC_{10} - 0.5	SC_{12} - 0.5
SC_2 - 0.333	SC_5 - 0.5	SC_7 - 0.5	SC_9 - 0.5	SC_{11} - 0.5	SC_{13} - 0.5
SC_3 - 0.292					

Table 4: Sub-criteria weights associated to each criterion

Weight of Criteria
Criterion 1 – 0.173913
Criterion 2 – 0.195652
Criterion 3 – 0.195652
Criterion 4 – 0.152174
Criterion 5 – 0.152174
Criterion 6 – 0.130435

Table 5: Criteria weights (top from the hierarchical structure)

Step 6: accident with an FPSO - Floating, Production, Storage, and Offloading Platform (Macaé, Rio de Janeiro State, Brazil)

Up to the previous step the generic decision model that provides the classification for any oil spill was defined. In this step, a specific oil spill will be subject to classification. This will be the article case study.

An accident with an FPSO, 80 kilometers out at sea from the city of Macaé, in the north of Rio de Janeiro State, caused a temporally reduction of 2% in Brazilian oil production for the year 2002. The risk of a platform-ship sink was very high, as well as the risk of spilling the 12 million liters of stored oil on the vessel itself. The coastal region of this part of the Rio de Janeiro State contains several sensitive natural environments, including coastal lakes, river mouths, mangroves, sandy beaches, rocky slopes, colonies of sea birds, isolated environments beyond the reach of fishing and tourism. The input data is shown in Table 6. These data are taken to the fuzzy sets defined in Figure 6 and provide the results shown in Table 7 and 8. They represent the matrixes of membership values of categories against criteria for each of the sub-criteria (lowest hierarchical level) and the criteria (higher hierarchical level), respectively.

The final result is the classification shown in Table 8(b). When defining the fuzzy sets it is necessary to identify how they contribute to the alternative classification. Experts will be important for this definition. For SC_2 sub-criterion (type of oil), for example, the lower the °API, the easier to remove it from the water, and therefore, the higher the contribution of such oil spills to the local level sorting. In contrast, for a sub-criterion as SC_{10} (adequacy of response equipment), the most appropriate are the equipment for oil removal, the greater the contribution to the oil spill to classify as local level. The table 7 shows how each of the criteria contributes to the final classification.

Sub-criteria	Value
1	12 million liters = 12.000 m^3
2	“crude oil”, API degree group IV, equivalent to 10° API
3	Spilling period: 0,0 hours
4	Distance from the coast: 80 km
5	There was not any oil spill. Grade 10,0
6	Medium. Grade 6,0
7	Yes. Grade 10,0
8	Yes. Grade 6,0
9	Yes. Grade 5,0
10	Some workers had to swim 40 minutes to reach the tug boat. Grade 6,0
11	Grade 7,0
12	Yes, the sinking of P-36 platform also in Campos basin. Grade 8,0
13	Grade 3,0

Table 6: Input data for the case study

Step 7: The sensitivity analysis for this problem should take into account that this model must provide fast decision support. For this reason it is important that the weights be well defined so that the model is ready at the time the decision support system needs to be used. An on-going research by the authors is focusing on a robustness analysis (as proposed by Roy [22]) of the TODIM-FSE and will be the subject of a forthcoming article.

Sub-criteria	Categories		
	LL	**RL**	**NL**
SC_1	0	0	1
SC_2	1	0.22	0
SC_3	1	0	0

(a)

Sub-criteria	Categories		
	LL	**RL**	**NL**
SC_4^*	0.94	0	0.08
SC_5	0	0	1

(b)

Sub-criteria	Categories		
	LL	**RL**	**NL**
SC_6	0	0.8	0.12
SC_7	0	0	1

(c)

Sub-criteria	Categories		
	LL	**RL**	**NL**
SC_8	0	0.8	0.12
SC_9	0.02	1	0.02

(d)

Sub-criteria	Categories		
	LL	**RL**	**NL**
SC_{10}^*	0.22	0.8	0
SC_{11}^*	0.76	0.36	0

(e)

Sub-criteria	Categories		
	LL	**RL**	**NL**
SC_{12}	0	0.16	0.88
SC_{13}	0.52	0.4	0

(f)

Table 7: Matrixes of membership values of categories against sub-criteria for each one of the six criteria from the hierarchical structure from figure 2. Marked with an asterisk are the sub-criteria where the larger its value, the lower its contribution for the alternative to belong into the highest category. In this table the values have already been altered to serve as input for calculating the intermediate value functions. The names LL, RL and NL respectively indicate *Local Level, Regional Level* and *National Level.*

Criteria	Categories		
	LL	RL	NL
C_1	1	0	0.3
C_2	0.82	0	1
C_3	0	0.81	1
C_4	0	1	0.14
C_5	0.91	1	0
C_6	0	0.37	1

(a)

Final Response

LL	RL	NL
0	0.59	1

(b)

Table 8: (a) Matrix of membership values of categories against criteria. Each component represents the $\xi_i$value described in section 2.6. The values calculated in each row (criterion C_j) represent the classification that would be given to the oil spill if only the sub-criteria of criterion C_i was taken into account. (b) the intermediate evaluation stored in table 8(a) is brought to the level above and the final classification is obtained. The classification ***national level*** was adopted for this spill.

4. Discussion and Conclusion

This paper provides an alternative multi-criteria sorting methodology, to support the construction of decision models. The structure and procedures for application are fully described. A case study have attempted to illustrate how the constructed model may be put into practice. It is also possible to compare TODIM-FSE with alternative multi-criteria decision aid classification methodologies available. One well-known sorting approach is the ELETRE TRI, described by Brito et al [23] and Dias et al [24]. In this method each alternative is compared with stable references, previously established by deciders. The AHP, described by Saaty [17] and the MACBETH, by Bana e Costa and Vansnick [25], were both originally constructed to solve ranking problems. However, it is also possible to use them to classify alternatives such as those described in Bana e Costa and Oliveira [26]. Using these methods the categories are built experimentally, together with decision makers, after the construction of the model. The borders for each category will depend on a set of previously defined alternatives or even on fictitious data, used by the deciders as references. Generally, a great deal of information is required in order to build the categories within these methodologies. A comparative analysis will reveal that in terms of the aforementioned elements, the TODIM-FSE is similar to the ELECTRE TRI method, in that each alternative is compared to a stable reference, set up by petroleum-study specialists.

One significant characteristic of the TODIM-FSE method is its ability to solve the decision problem as presented in this article. This is because it is not common to have oil spills (and available information about them) and be able to evaluate the models constructed, according to the demands involved in the AHP, MACBETH and similar methods.

Another remarkable feature of TODIM-FSE relates to the possibility of merging elements from fuzzy logic and Prospect Theory. For, in this way, it is possible to take into account the imprecision commonly present in human judgments. It is also important to underline the fact that knowledge of fuzzy logic is needed to build the models themselves; however this same knowledge is not needed to actually use the models. Thus, once the models are constructed by a decision analyst, the users will incorporate their preferences using scales without any fuzzy characteristic. This advantage undoubtedly contributes towards the comparative ease of using the TODIM-FSE method. The use of Prospect Theory, embedded in TODIM equations, allows the decision makers the possibility of considering risk in the decision problem. This is completely suitable for the oil spill situation presented in this article.

Finally, the TODIM-FSE model constructed and the applications in well-defined oil spill situation, have contributed towards verifying the quality of the method. Additionally, the feasibility of embedding the model within the SISNOLEO structure is apparent and applicable, in terms of assisting petroleum analysts in improving their decision-making regarding oil spills contingency actions.

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