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A Comparative Analysis of Applied FMADM in a Serious Games Evaluation Model

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Abstract

In recent years, Serious Games are being used as an innovative pedagogical strategy to achieve more effective learning in various fields of knowledge, but in order to use them effectively, it is essential to evaluate them systematically to obtain solid evidence of their impact.

To this end, the integration of fuzzy multi-attribute decision making (FMADM) methods will be beneficial for the evaluation of Serious Games in order to weight their evaluation criteria according to the desired context, as these FMADMs have the capacity to take into account the imprecision and uncertainty of human judgements.

In this paper, we will present a comparative analysis of various fuzzy multi-attribute decision making (FMADM) techniques, namely the fuzzy DEMATEL and fuzzy SWARA methods applied in the Serious Games evaluation model in which the fuzzy AHP method has been used. In order to find the ranking of various dimensions responsible for better decision making and the ability to accurately reflect human judgment for the evaluation of Serious Games in a given context.

According to the results obtained, we find that the fuzzy AHP method was the best suited to our decision problem, despite the identical ranking of the criteria obtained.

Keywords: Serious Game, evaluation model, FMADM, fuzzy AHP, fuzzy DEMATEL, fuzzy SWARA.

1. Introduction

Learning with Serious Games remains a process focused on educational objectives (De Gloria et al., 2014), therefore, systematic evaluation through the integration of a reliable evaluation process (Petri et al., 2016), will further enable the necessary information to be obtained, in order to have a global view on its capabilities before its implementation in a training course.

Since proposed evaluation models often evaluate Serious Games based on subjective preferences (Bellotti et al., 2013), it is better to consider this situation as a multi-criteria decision making problem.

To solve this multi-criteria problem, we used multi-attribute decision making (MADM) methods, which are part of the field of operations research, grouping together a set of methods for making decisions where several criteria are involved and need to be evaluated.

According to (Kahraman et al., 2015), we have noted the existence of several MADM methods for pairwise comparison and determination of criteria weighting values.

The best known of which are, but not limited to, the Hierarchical Process Analysis method (AHP) proposed by (Saaty, 1980), which is a method based on pairwise comparison of the criteria at each level of the hierarchy, in order to weight them precisely according to human judgment.

There is also the Decision-Making Trial and Evaluation Laboratory (DEMATEL), a multi-criteria decision method developed by the Geneva-based Battelle Memorial Institute (Gabus & Fontela, 1972) to analyze the relationship between the complex and interrelated criteria of a structural model.

In addition, the Stepwise Weight Assessment Ratio Analysis (SWARA) method introduced by (Keršulienė et al., 2010), as a tool for estimating criterion weights in multi-attribute problems, taking into account the preferences of decision makers.

We also find other methods such as BWM (Rezaei, 2015), MACBETH (Costa & Vansnick, 1999), FUCOM (Pamucar et al., 2018), but their applications in the scientific literature remain limited (Kahraman et al., 2015), which is why we focus our comparative analysis on the AHP, SWARA and DEMATEL methods.

The fuzzy logic concept introduced by (Zadeh, 1965) has been integrated with a variety of methods to address the inherent imprecision and ambiguity of data in human decision-making. These fuzzy methods have found extensive applications across various domains such as technology (Muhammad & Cavus, 2017), health (Sumrit, 2020), and logistics (Ulutas et al., 2020).

In this paper, we propose a comparative analysis between fuzzy pairwise comparison methods, namely fuzzy DEMATEL and fuzzy SWARA. The results obtained will be compared with those obtained by the fuzzy AHP method applied in the indoor study (Omari et al., 2020). In order to evaluate the performance and capabilities of these methods to accurately reflect human judgement.

This paper is divided into 5 sections. The next section presents the state of the art of our study, and then in the second section the general context of our study is presented. The use of the fuzzy DEMATEL method is introduced in section 3. The use of the fuzzy SWARA method is presented in section 4. A discussion with the presentation of the results is illustrated in section 5 and finally, a conclusion will close this study.

2. State of Art

The fuzzy multi-attribute decision making (FMADM) approach is the best known branch of the FMCDM methods (Mardani et al., 2015), which refers to decision making in a discrete decision space that is characterized by the explicit description of the set of alternatives and finite attributes involved in the decision process in a fuzzy environment (Liu & Deng, 2020).

According to (Abdullah, 2013), the fusion of fuzzy set theory with MADM methods has been ideally suited to deal with the ambiguity encountered in solving multi-attribute problems in real-life decision situations, to allow decision-makers to describe the problem environment and its properties more closely to reality, and consequently to build a rational decision making model.

The most commonly used FMADM methods in the literature can be classified as fuzzy pairwise comparison based methods, fuzzy distance based methods and fuzzy outranking based methods (Figure 1).

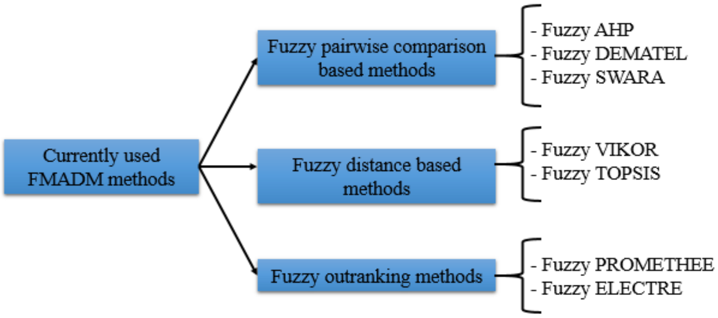

Figure 1 : Classification of commonly used FMADM methods

- ✓ **Fuzzy pairwise comparison based methods**

Fuzzy pairwise comparison methods offer the decision-maker the possibility to compare criteria with each other using a rating scale (Siebert, 2018), with the aim of calculating relative importance values for each criterion in a fuzzy environment.

- ✓ **Fuzzy distance based methods**

Fuzzy distance methods are based on an aggregation function representing the "proximity to the ideal" (Opricovic & Tzeng, 2004). They are used to solve problems with conflicting criteria.

- ✓ **Fuzzy outranking methods**

Outranking methods are based on the concept of (Roy, 1968), to provide decision support to decision makers in the form of the best alternative or a partial or complete ranking of alternatives (Roy, 1968).

Although all methods have the capacity to take into account the imprecision and uncertainty of human judgements, each method has its advantages and disadvantages depending on the context in which it is used. This explains why some FMADM methods are better suited to particular decision-making problems than others.

In a scientific research approach, we believe that it is reasonable to exploit in turn the FMADM methods based on fuzzy pair comparison that are most appropriate to our Serious Game evaluation problem.

3. Context of the Study

FMADM methods are used to solve discrete-space decision problems requiring intra- and inter-attribute comparisons involving human judgements. For many fuzzy multi-attribute decision problems, weighting indicators are included among the procedures for solving multi-attribute decision problems (Odu, 2019). Therefore, the decision maker must choose a method to extract these preferences efficiently, in order to obtain suitable weights for each criterion.

We note that there is no consensus on the methods. Although all methods have the capacity to take into account the imprecision and uncertainty of human judgements, each method has its advantages and disadvantages depending on the context in which it is applied. This explains why some FMADM methods are more appropriate than others for specific decision problems.
In a scientific research approach, we believe that it is reasonable to exploit in turn the FMADM methods that are most appropriate to our problem of evaluating the Serious Game.(Figure 2)

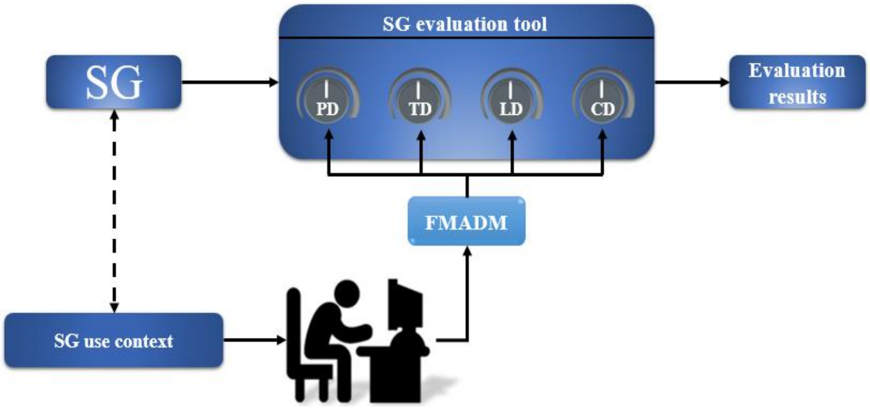

Figure 2 : Evaluation model for Serious Games (Omari et al., 2020)

This model has been designed based on four dimensions deemed necessary that a Serious Games must satisfy in order to fulfil the task for which it has been developed. These dimensions, pedagogical (PD), technological (TD), ludic (LD) and behavioral (BD), will be measured according to several well defined criteria represented below:

Table 1: Dimensions and criteria

Dimension	Measurement criteria
Pedagogical (PD)	– Targetedskills (Ts) – Pedagogical consideration (Pc) – Learning result (Lr) – Error management (Em)
Technological (TD)	– Game design (Gd) – Performance (P) – User interfaces (Ui) – Usability (U)
Ludic (LD)	– Challenge (C) – Fun (F) – Gameplay (G) – Immersion (I)
Behavioral (BD)	– Motivation (M) – Engagement (E) – User experience (Ue)

The importance of each dimension depends on the context in which the Serious Game is used. For example, if the Serious Game is used in a purely formative context, the pedagogical dimension will be considered as dominant compared to the other dimensions.

Therefore, and depending on the use context of the Serious Game, it is essential to weight this selection of the four dimensions and the weighting of their multiple criteria using a fuzzy multi-attribute decision making method FMADM.

In this paper, we exploit in the same context applied in the study (Omari et al., 2020), the two other types of fuzzy multi-attribute decision-making methods, namely fuzzy DEMATEL and fuzzy SWARA.

4. Weighting Process of the Criteria Using the Fuzzy Dematel Method

The Decision-Making Trial and Evaluation Laboratory (DEMATEL), is a multi-criteria decision method developed by the Geneva research centre of the Battelle Memorial Institute (Gabus & Fontela, 1972), with the aim of analyzing the relationships between the complex and interrelated criteria of a structural model.

The DEMATEL method is based on the theory of graphs, more precisely digraphs, allowing to project and solve problems visually, to better grasp causal relationships in a visible way (Hsu et al., 2007).

Although DEMATEL is widely accepted as one of the best methods for solving the causal relationship between the evaluation criteria of a multi-criteria decision problem. Its relationships are usually given by precise values when building a structural model, which are considered insufficient and uncertain when it comes to human judgements. Thus, fuzzy logic is adopted with the DEMATEL method to solve such a problem (Farooque et al., 2020).

As shown in Figure 3, the process of weighting the criteria using the fuzzy DEMATEL method goes through successive stages for all the criteria that make up the Serious Game evaluation model.

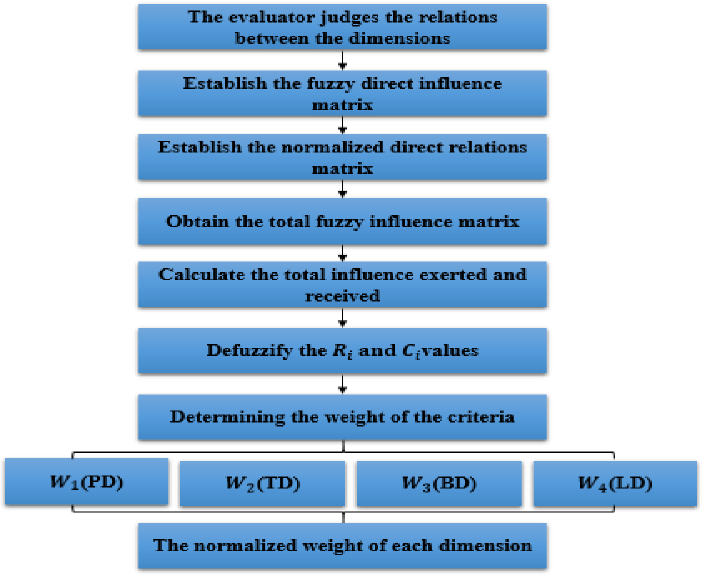

Figure 3 : Weighting process using the fuzzy DEMATEL method

The scenario for weighting the evaluation criteria of a Serious Game using the fuzzy DEMATEL method consists of seven steps:

Step 1: Evaluate the relations between the dimensions using a fuzzy language scale as shown in the table below:

To handle the imprecision of experts' opinions and expressions in decision-making, linguistic ambiguities are represented by converting linguistic variables into fuzzy numbers. The scale of linguistic variables with triangular fuzzy numbers used here is shown in Table 2.

(Wu & Lee, 2007) previously applied this fuzzy linguistic scale in a fuzzy DEMATEL analysis.

Table 2: Table of fuzzy linguistic comparisons

Linguistic terms	**Linguistic value**
Very high influence (VHI)	(0.75, 1.0, 1.0)
High Influence (HI)	(0.5, 0.75, 1.0)
Low Influence (LI)	(0.25, 0.5, 0.75)
Very Low Influence (VLI)	(0, 0.25, 0.5)
No influence (NI)	(0, 0, 0.25)

Step 2: Establish the fuzzy direct influence matrix of the group

In this step, the evaluator is asked to indicate the degree of direct influence that each factor/item i has on each factor/item j, which is noted $\tilde{u}_{ij}$ forming a fuzzy direct influence matrix of the group called $\tilde{A}$.

$$\tilde{A} = [\tilde{u}_{ij}]_{n\times n}$$

where $\tilde{u}_{ij}$=(l_{ij}, m_{ij}, u_{ij}) is a triangular fuzzy numbers.

This is done by keeping the same comparison judgment defined in the initial study (Omari et al., 2020), while relying on the scales representing the range from "no influence" to "very strong influence".

We have obtained:

$$\tilde{A} = \begin{pmatrix} \text{NI} & \text{VHI} & \text{LI} & \text{LI} \\ \text{VHI} & \text{NI} & \text{LI} & \text{VLI} \\ \text{VHI} & \text{HI} & \text{NI} & \text{VLI} \\ \text{VHI} & \text{LI} & \text{VLI} & \text{NI} \end{pmatrix} \qquad (1)$$

Step 3: Establish the normalized direct relations matrix $\widetilde{X}$:

To transform the different criteria scales into a comparable scale, the normalized direct correlation matrix $\tilde{X} = [\tilde{X}_{ij}]$ can be obtained by the following equations (2) and (3).

$$\tilde{X} = \frac{\tilde{A}}{r} \qquad (2)$$

Where:

$$r = \max\left[\max_{1\le i\le n} \sum_{j=1}^{n} u_{ij}\, , \max_{1\le j\le n} \sum_{i=1}^{n} u_{ij}\right] \; i, j = 1,2, \ldots\ldots, n \qquad (3)$$

The result obtained is as follows:

$$\tilde{X} = \begin{pmatrix} (0,0,0) & (0.25,0.333,0.333) & (0.083,0.167,0.25) & (0.083,0.167,0.25) \\ (0.25,0.333,0.333) & (0,0,0) & (0.083,0.167,0.25) & (0,0.083,0.167) \\ (0.25,0.333,0.333) & (0.167,0.25,0.333) & (0,0,0) & (0,0.083,0.167) \\ (0.25,0.333,0.333) & (0.083,0.167,0.25) & (0,0.083,0.167) & (0,0,0) \end{pmatrix}$$

Step 4: Obtain the total fuzzy influence matrix

In this step, the total relationship matrix ($\tilde{T}$) calculates the overall influence of one factor on the others and vice versa, and is the basis for defining the overall degree of influence of each factor, is calculated based on the normalized direct relations matrix $\tilde{X}$.

Once the initial direct relation fuzzy matrix is obtained, we can separate the fuzzy numbers in this matrix into separate sub-matrices i.e X_l, X_m *and* X_u.

As a result, any of the sub-matrices X_l, X_m *or* X_u just seems like the sub-stochastic matrix obtained from an absorbing Markov chain matrix by deleting all rows and columns associated with the absorbing states (Lin & Wu, 2008).

Following (Papoulis & Pillai, 2002), it was proven that $\lim_{n\to\infty} (X_s)^n = O$ and $\lim_{n\to\infty} (I + X_s + X_s^2 + \cdots + X_s^n) = (I - X_s)^{-1}, \forall\, s = l, m, u,$ where O is the null matrix and I is the identity matrix.

Therefore, to generate each element of the total fuzzy influence matrix $\tilde{T}$, these relations have to be calculated:

$$\tilde{T} = \tilde{X}\left(I - \tilde{X}\right)^{-1} \qquad (4)$$

Where $\left(I - \tilde{X}\right)^{-1}$ is called the fundamental matrix for the absorbing Markov chain, where I is an identity matrix of the same size as $\tilde{X}$.

So: $\tilde{T} = \left(t_{ijl}, t_{ijm}, t_{iju}\right)$ is the overall influence of each criterion i against criterion j.

$$\left[t_{ijl}\right]_{n\times n} = X_l (I - X_l)^{-1}, i, j \in \{1,2, \ldots, n\} \qquad (5)$$

$$X_l = \begin{pmatrix} 0 & 0.25 & 0.083 & 0.083 \\ 0.25 & 0 & 0.083 & 0 \\ 0.25 & 0.167 & 0 & 0 \\ 0.25 & 0.083 & 0 & 0 \end{pmatrix}$$

With using the following instruction Y = inv(X) on MATLAB, we were able to calculate the$(I - X_l)^{-1}$.

$$(I - X_l)^{-1} = \begin{pmatrix} 0.131286 & 0.310705 & 0.120166 & 0.094274 \\ 0.310705 & 0.099419 & 0.11751 & 0.025892 \\ 0.334606 & 0.260913 & 0.049627 & 0.027884 \\ 0.308714 & 0.169295 & 0.039834 & 0.025726 \end{pmatrix}$$

After applying formula (5), we obtain the following matrix:

$$[t_{ijl}] = \begin{pmatrix} 0.131286 & 0.310705 & 0.120166 & 0.094274 \\ 0.310705 & 0.099419 & 0.11751 & 0.025892 \\ 0.334606 & 0.260913 & 0.049627 & 0.027884 \\ 0.308714 & 0.169295 & 0.039834 & 0.025726 \end{pmatrix}$$

$$[t_{ijm}]_{n\times n} = X_m(I - X_m)^{-1}, i, j \in \{1,2, \dots, n\} \qquad (6)$$

By applying formula (6), we obtain the following matrix:

$$[t_{ijm}] = \begin{pmatrix} 0.440607 & 0.626972 & 0.371539 & 0.323311 \\ 0.650194 & 0.346829 & 0.353677 & 0.250074 \\ 0.696636 & 0.585889 & 0.236082 & 0.267937 \\ 0.646621 & 0.482286 & 0.285799 & 0.171777 \end{pmatrix}$$

$$[t_{iju}]_{n\times n} = X_u(I - X_u)^{-1}, i, j \in \{1,2, \dots, n\} \qquad (7)$$

After applying formula (7), we find the following matrix:

$$[t_{iju}] = \begin{pmatrix} 0.994421 & 1.191074 & 0.93863 & 0.85356 \\ 1.171548 & 0.874477 & 0.88703 & 0.75314 \\ 1.249651 & 1.199442 & 0.74616 & 0.80335 \\ 1.165969 & 1.065551 & 0.82566 & 0.60669 \end{pmatrix}$$

Step 5: Calculate the total influence exerted and received.

After obtaining the matrix $\tilde{T}$, the row sum (R) and column sum (C) of the total fuzzy influence matrix based on the formula are estimated in the equations below:

$$R_i = [r_{ij}]_{n\times 1} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}\right) \; i, j = 1,2, \dots\dots, n \qquad (8)$$

$$C_i = [c_{ij}]_{1\times n} = \left(\sum_{i=1}^{n} l_{ij}, \sum_{i=1}^{n} m_{ij}, \sum_{i=1}^{n} u_{ij}\right) \quad i, j = 1,2, \dots\dots, n \qquad (9)$$

Where:

R_i: The total influence exerted on the criteria.

C_i: The total influence received from the criteria.

l_{ij}: The smallest possible value.

m_{ij}: The most promising value.

u_{ij}: The highest possible value.

After applying the (8) formula, we obtain the following matrix:

$$R_i = \begin{pmatrix} 0.656432 & 1.762429 & 3.977685 \\ 0.553527 & 1.600774 & 3.686192 \\ 0.673029 & 1.786544 & 3.998605 \\ 0.543568 & 1.586484 & 3.663877 \end{pmatrix}$$

The total influence exerted on the criteria R_i is the sum of the rows in the ith row of the $\tilde{T}$ matrix and shows the sum of the direct and indirect effects of factor/element i on the other factors/elements.

Similarly, after applying the (9) formula, we obtain the following matrix:

$$C_i = \begin{pmatrix} 1.085311 & 2.434058 & 4.58159 \\ 0.840332 & 2.041977 & 4.330544 \\ 0.327137 & 1.247097 & 3.39749 \\ 0.173776 & 1.013099 & 3.016736 \end{pmatrix}$$

C_i denotes the sum of the columns of the jth column of the $\tilde{T}$ matrix and shows the sum of the direct and indirect effects that factor/element j received from the other factors/criteria.

Step 6: Defuzzify the $\mathbf{R_i}$ and $\mathbf{C_i}$ values

"Defuzzification" refers to the process of selecting a specific net element based on the fuzzy output set. The commonly used defuzzification method is the centroid method, commonly known as the Centre of Area (COA) or Centre of Gravity (COG) (Si et al., 2018).

Because that, we adopt the centroid method (Si et al., 2018), to determine the net values of the fuzzy numbers, with the following formula:

$$y = l + \frac{(m-l)+(u-l)}{3} \qquad (10)$$

Following the application of formula (10), we obtain the following results:

Table 3: Net values of fuzzy numbers

$\tilde{R}_i^{def}$	$\tilde{C}_i^{def}$
2.869514	3.599484
2.644996	3.205381
2.895069	2.270548
2.626587	1.960753

The sum of ($\tilde{R}_i^{def}$ + $\tilde{C}_i^{def}$) provides an index of the strength of the given and received influences, that shows the degree of the central role that factor i holds in the problem.

If $(\tilde{R}_i^{def} + \tilde{C}_i^{def})$ is positive, then factor i affects other factors, and if $(\tilde{R}_i^{def} + \tilde{C}_i^{def})$ is negative, then factor i is influenced by other factors.

Step 7: Calculate the weights of the criteria by applying the vector length method:

We use the following formula to measure the importance of the criteria.

$$w_i = \left[\left(\tilde{R}_i^{def} + \tilde{C}_i^{def}\right)^2 + \left(\tilde{R}_i^{def} - \tilde{C}_i^{def}\right)^2\right]^{1/2} \qquad (11)$$

Table 4: The weight of the criteria

Dimension	Weight
PD	6.5100529
TD	5.8771539
BD	5.2032324
LD	4.6354094

Then, the weight of any criterion can be normalized as follows:

$$w_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad i, j = 1,2, \ldots\ldots, n \qquad (12)$$

Table 5: The normalized weight of each dimension

Dimension	Weight normalized
PD	0.293
TD	0.264
BD	0.234
LD	0.209

4.1 Results of the application of the fuzzy DEMATEL method

After applying the formulas above, we obtained the following results.

Table 6: Dimension weights obtained with the fuzzy DEMATEL method

Dimension	Weight	Ranking
PD	0.293	1
TD	0.264	2
BD	0.234	3
LD	0.209	4

The ranking obtained by the fuzzy DEMATEL method shows that the PD is better than the TD, BD and LD dimensions respectively. This result reinforces the one obtained by fuzzy AHP in (Omari et al., 2020).

5. Weighting process of the criteria adopted using the Fuzzy SWARA method

(Keršuliene et al., 2010) introduced the Stepwise Weight Assessment Ratio Analysis (SWARA) method, as a method for estimating weights and evaluating criteria, taking into account the preferences of decision makers during the weighting process (Keršuliene et al., 2010).

According to (Perçin, 2018), SWARA is one of the new decision-making methods, which has been applied to derive the relative importance weights of the criteria. In this method, the preferences of the decision makers are considered as the most important deciding factor in the calculation of the criteria weights.

These preferences are often fuzzy and difficult to estimate by exact numerical values, so fuzzy logic is used with this method, in order to provide a very appreciable flexibility to human reasoning, which makes it possible to take into account imprecisions and uncertainties in the decision makers' judgements (Sumrit, 2020).

The evaluation process, as shown in Figure 4, ranks the set of evaluation aspects according to importance, then the evaluator expresses the relative importance of the criterion in relation to the previous one using the linguistic values transformed into triangular fuzzy numbers, and then the calculations of the weights of the set of aspects are started.

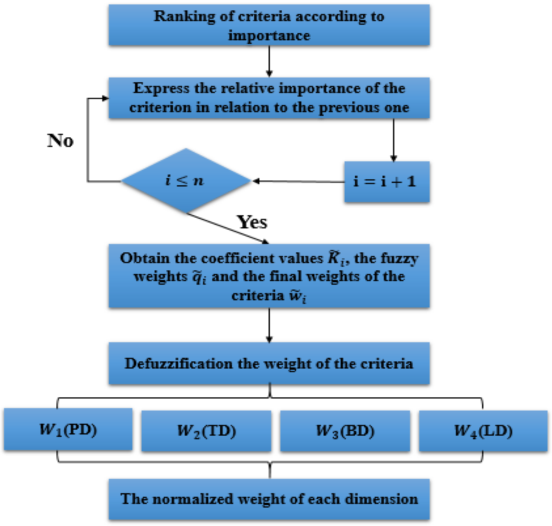

Figure 4: Weighting process using the Fuzzy SWARA method

The scenario for weighting the evaluation criteria of a Serious Game using the Fuzzy SWARA method consists of four steps:

Step 1: The dimensions should be ordered in descending order according to their expected meanings, i.e. the most significant dimension is assigned the first rank and the least significant dimension the last rank.

Step 2: From the second dimension, the evaluator expresses the relative importance of the dimension compared to the previous one for all dimensions.

Table 7: Comparative importance of the mean value

Ranking of dimensions	Linguistic value	$\tilde{P}_i$
PD	-	-
TD	Moderately less important compared to PD	(2/3, 1, 3/2)
BD	Moderately less important compared to TD	(2/3, 1, 3/2)
LD	Moderately less important compared to BD	(2/3, 1, 3/2)

The matrix obtained after the evaluator's judgement.

$$C_i = \begin{pmatrix} 1 & 1 & 1 \\ 0.667 & 1 & 1.500 \\ 0.667 & 1 & 1.500 \\ 0.667 & 1 & 1.500 \end{pmatrix}$$

Step 3: Obtain the coefficient values $\widetilde{K}_i$, the fuzzy weights $\tilde{q}_i$ and the final weights of the criteria $\widetilde{w}_i$.

The coefficient value $\widetilde{K}_i$ is calculated as:

$$\widetilde{K}_i = \begin{cases} \tilde{1} & i = 1 \\ \tilde{S}_i + 1 & i > 1 \end{cases} \tag{13}$$

Where $\widetilde{K}_i = (\widetilde{K}_i^l, \widetilde{K}_i^m, \widetilde{K}_i^u)$

Table 8: Values of the coefficient $\widetilde{K}_i$

Dimension			
PD	1.000	1.000	1.000
TD	1.667	2.000	2.500
BD	1.667	2.000	2.500
LD	1.667	2.000	2.500

Recalculated fuzzy weights are obtained with the formula below:

$$\tilde{q}_i = \begin{cases} \tilde{1} & i = 1 \\ \frac{\tilde{q}_{i-1}}{\widetilde{K}_i} & i > 1 \end{cases} \tag{14}$$

Where $\tilde{q}_i = (\tilde{q}_i^l, \tilde{q}_i^m, \tilde{q}_i^u)$

Table 9: The $\tilde{q}_i$ values

Dimension			
PD	1.000	1.000	1.000
TD	0.400	0.500	0.600
BD	0.160	0.250	0.360
LD	0.064	0.125	0.216

Final relative weights of the criteria are calculated using the formula below:

$$\widetilde{w}_i = \frac{\tilde{q}_i}{\sum_{k=1}^{n} \tilde{q}_i} \qquad (15)$$

Table 10: The $\widetilde{w}_i$ values

Dimension			
PD	0,460	0,533	0,616
TD	0,184	0,267	0,369
BD	0,074	0,133	0,222
LD	0,029	0,067	0,133

Where: $\widetilde{w}_i$ is the relative weight of the criterion and i is the number of criteria $\widetilde{w}_i = (w_i^l, w_i^m, w_i^u)$.

Step 4: Defuzzification

The centroid method (Centre of gravity (COG) or Centre of area (COA)) has been used to determine the net values of the fuzzy numbers (the defuzzification) (Si et al., 2018), with the following formula:

$$w_i = w_i^l + \frac{\left(w_i^m - w_i^l\right) + \left(w_i^u - w_i^l\right)}{3} \qquad (16)$$

Table 11: The weight of the criteria

Dimension	Weight
PD	0.585
TD	0.329
BD	0.183
LD	0.101

Then, the weight of any criterion can be normalized as follows:

$$w_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad i, j = 1,2, \dots \dots, n \tag{17}$$

Table 12: The normalized weight of each dimension

Dimension	Weight
PD	0.489
TD	0.274
BD	0.153
LD	0.084

5.1 Results of the application of the fuzzy SWARA method

After applying formulas, we obtained the results presented below.

Table13: Dimension weights obtained with the fuzzy SWARA method

Dimension	Weight	Ranking
PD	0.489	1
TD	0.274	2
BD	0.153	3
LD	0.084	4

The result obtained by the fuzzy SWARA method classifies the dimensions as PD>TD>BD>LD, which shows that DP is the best dimension.

6. Results discussion

For many fuzzy multi-attribute decision making problems, weighting indicators are included among the procedures in the process of solving multi-criteria decision problems (Odu, 2019). Therefore, the decision-maker has to choose a method to extract efficiently these preferences, in order to obtain suitable weights for each criterion.

Considering the wide variety of these methods and in order to help the decision-maker to make a relevant and judicious choice, we will in the following analyze and discuss the results obtained.

According to table 14 below, we notice a difference between the weights obtained for each dimension after the application of the FMADM methods on the same Serious Games evaluation model, this is justified by the difference in calculation between the fuzzy methods.

Table 14: Results of fuzzy multi-attribute decision making methods

	Fuzzy AHP	**Fuzzy SWARA**	**Fuzzy DEMATEL**	**Ranking**
PD	0.557	0.489	0.293	1
TD	0.267	0.274	0.264	2
BD	0.120	0.153	0.234	3
LD	0.056	0.084	0.209	4

This difference can be summarized in three main points:

- ✓ **The number of comparisons adopted in each fuzzy method.**

For the fuzzy AHP method, the comparison results in the need to apply $\frac{n(n-1)}{2}$ comparisons between criteria. In contrast, the fuzzy DEMATEL method starts with a comparison between all criteria in both directions which results in the need to apply $n(n-1)$comparisons. This is in contrast to the fuzzy SWARA method, which requires $(n-1)$ comparisons.

- ✓ **The difference between the representations of the problems for each method.**

In the fuzzy AHP method, the representation of the decision-making problem is hierarchical. As for the fuzzy DEMATEL method, it is based on graph theory to allow a visual projection of the problems.

In contrast to all these methods, the Fuzzy SWARA method does not use a graphical or hierarchical representation, but estimates the evaluation weights of the criteria, taking into account only the preferences of the decision makers.

- ✓ **Checking the consistency measure in the judging process.**

After the application of FMADM methods in the Serious Games evaluation model, we noticed a difference between the calculation processes adopted in each fuzzy method.

Which allowed us to observe the point that favors the application of fuzzy AHP in this study, which is the ability to have the possibility of validating the coherence of the results through the threshold of the RC coherence ratio.

This ratio is defined as the ratio between the coherence index of the evaluation matrix (CI) and the coherence index of a random matrix (RI), according to (Saaty, 1995) the threshold value of the coherence ratio must be less than or equal to 10%, in order to judge the validity of the evaluator's choice.

In our case, we obtained a RC value that is equal to 5.7% which implies that our choice of criteria weighting is valid.

Due to the need to respect mathematical transitivity in pairwise comparisons of criteria (Pamucar et al., 2018), the main disadvantage of the fuzzy DEMATEL and fuzzy SWARA methods is the lack of consistency in their application processes, i.e. the inability to validate the results obtained, which is why these two methods have been used less in the literature.

The results of this study clearly indicate the justification for adopting the fuzzy AHP method in the Serious Games evaluation model. This finding was also confirmed by the study (Omari et al., 2021). For this reason, the application of fuzzy AHP has been strongly adopted in the literature (Kahraman et al., 2015).

7. Conclusion

In this paper, we presented an analysis between pairwise comparison methods in a fuzzy environment, in order to judge the reliability and consistency of the judgments obtained by these fuzzy methods applied in the evaluation model of Serious Games.

The chosen methods (fuzzy DEMATEL, fuzzy SWARA) were applied in the same context as the fuzzy AHP method, in order to be able to judge in an objective way which of these methods is the most adequate to our decision-making problem.

The results obtained in this study clearly show the usefulness and reliability of using the fuzzy AHP method, in order to have a flexible and adequate Serious Games evaluation model according to the desired evaluation context.

In our future work, we suggest combining the fuzzy AHP method with an objective weighting method to determine a more justified set of weights for the evaluation criteria of Serious Games.

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