Project Ranking with Uncertainty using Multicriteria Decision Method and Fuzzy

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Abstract: Decision-makers are frequently faced with the task of picking projects to be carried out. Generally, there aren't enough resources to fund all of them. Because numerous criteria to be examined at the same time in this task, decision requires the assistance of a tool or approach. Multi-Criteria Decision-Making strategies can be helpful. However, as with all project estimation, uncertainty must be addressed. Using the TOPSIS method and fuzzy numbers, this article presents a way for incorporating uncertainty in project selection. It is exemplified by the application of selection method over a set of 11 real projects.

1 INTRODUCTION

The selection of projects is a prevalent problem in businesses. Due to the fact that they must share resources, which are typically few and insufficient to run them all at the same time (Agapito et al., 2019; Dutra et al., 2014; Lee et al., 2020). The decision-makers must then choose a subset of them from among the candidates for execution (Abbassi et al., 2014). There are numerous approaches for making this selection, with ranking being one of them. Ranking is a useful tool that allows a choice based on structured forms of comparison, especially if objective criteria are specified, with the goal of better aligning with the companies' market objectives and desires (Perez and Gomez, 2014).

When applying formal methods for project selection, the chances of success in execution for the company increase (Dutra et al., 2014). Because, the choice for the correct project portfolio may avoid the waste of resources, which are scarces (Abbassi et al., 2014; Agapito et al., 2019).

This kind of decision, generally, is complex, once several criteria must be considered simultaneously (Tzeng and Huang, 2011). Specially for R&D projects, whose results, if not expected, may negatively impact the company's future (Lee et al., 2020).

To deal with this type of choice, a Multicriteria Decision Method (MCDM) may support the selection of project portfolio, because it is a tool for helping in complex engineering problems. Some of them offer the possibility of a final ranking, indicating the alternatives in order of preference (Mavrotas and Makryvelios, 2021; Wallenius et al., 2008). Preference Ranking Organization Method for Enrichment Evaluation II (PROMETHEE II), *VIseKriterijumska Optimizacija I Kompromisno Resenje* (VIKOR), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and *Elimination Et Choix Traduisant la Réalité* II (ELECTRE II) (Martins and Marcondes, 2020) are examples of MCDM. Sadi-Nezhad (2017) states their applications has been growing in academic publications.

However, as the decision must be made based on estimates, since uncertainty is inherent and unavoidable in this process (Bohle et al., 2015). Which indicates that it must be considered in the decision, as it can change the results obtained (Marcondes, 2021; Marcondes et al., 2017).

PMI (2021) presents an alternative to deal with uncertainty in estimation, using three-points. With it, instead of a single estimated value, decision must be made based on three (worst-case, most likely and best-case), using some approach to dealing with variation, as Monte Carlo simulation or fuzzy numbers (Deng, 2014; Marcondes, 2021; Wang, 2015).

Fuzzy numbers provide a convenient concept when working with imprecise numerical quantities, allowing for their proper representation and arithmetic manipulation (Deng, 2014). They are widely used in a variety of applications for handling practical challenges of many types in imprecision real-world

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contexts (Deng, 2014).

Marcondes (2021) proposed a way to deal with uncertainty in project selection using three-point estimation, ELECTRE II method and Monte Carlo simulation. This work proposes a change using fuzzy numbers relative preference relation, as presented by Wang (2015), to deal with uncertainty, instead of Monte Carlo simulation, and the use of TOPSIS method (instead of ELECTRE II). The selection method was adapted and numerical example was done over the same set of projects, allowing a comparison between both results.

The uncertainty addressed in this work is the one introduced in the estimation process, naturally, due to the error in values attributed to the decision criteria for each alternative. The example presented could have been done with other MCDMs. TOPSIS was chosen because it is one of the most used in the literature.

The remaining of this paper is organized as follow: Section 2 presents the principles of multicriteria decision methods, detailing TOPSIS; the importance of uncertainty in project selection problems and fuzzy numbers comparison is presented in Section 3; Section 4 proposes a method for selecting projects considering uncertainty; which is exemplified by a real problem in Section 5; Section 6 concludes the work.

2 MULTI-CRITERIA DECISION METHODS

When only one criterion is used to choose among alternatives, the process is relatively simple, as selecting the ones with the highest scores is all that is required. When more than one criterion is used, the decision becomes more difficult since the criteria must be examined simultaneously and, in some situations, there may be a conflict among them (Tzeng and Huang, 2011).

According to research, the usage of Multi-criteria Decision Methods (MCDM) in project selection is increasing (Sadi-Nezhad, 2017). These strategies allow one to order multiple options based on a variety of factors and then choose the best ranked. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is an MCDM able to generate a final ranking of the alternatives, comparing them with the ideal and non-ideal solutions. It is presented in the sequence.

2.1 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is a multi-criteria method for assessing and comparing the performance of potential solutions. The best option is the one that is the most similar to the ideal solution and the least similar to the non-ideal solution. For each criterion must be given a weight based on the importance to the decision-maker (Martins and Marcondes, 2020; Tzeng and Huang, 2011).

The TOPSIS method is executed by the steps described below (Martins and Marcondes, 2020; Tzeng and Huang, 2011).

Step 1 - Calculate the normalized r_{ij} in the decision matrix:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{m} f_{ij}^2}} \tag{1}$$

where:
j is the alternative ($j = 1, \ldots, m$)
i is the selection criteria ($i = 1, \ldots, n$)
f_{ij} is the value assigned to the alternative j in the criterion i

Step 2 - Calculate the weighted ς^{ij} for each r_{ij} in normalized decision matrix:

$$\varsigma^{ij} = w_i r_{ij} \tag{2}$$

where:
w_i is the weight of i^{th} criterion;
$\sum_{i=1}^{n} w_i = 1$.

Step 3 - Determine the ideal and negative solution:

$$\varsigma^* = (\underset{j}{max})\varsigma_{ij} | j \in J', (\underset{j}{min})\varsigma_{ij} | j \in J'' \tag{3}$$

$$\varsigma^- = (\underset{j}{min})\varsigma_{ij} | j \in J', (\underset{j}{max})\varsigma_{ij} | j \in J'' \tag{4}$$

where:
J' associated with positive impact criteria;
J'' associated with negative impact criteria.

Step 4 - Use Euclidean distance to calculate separation measures (D_j^* and D_j^- separations from the ideal and negative solutions, respectively):

$$D_j^* = \sqrt{\sum_{i=1}^{n} (\varsigma_{ij} - \varsigma_i^*)^2} \tag{5}$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} (\varsigma_{ij} - \varsigma_i^-)^2} \tag{6}$$

Step 5 - Calculate the relative proximity of the ideal solution:

$$C_j^* = \frac{D_j^-}{D_j^* - D_j^-} \tag{7}$$

Step 6 - Organize alternatives in ascending order of preference, taking into account the growing value of C_j^*. It is feasible to determine the best alternative using this ranking of preferences. (Opricovic and Tzeng, 2004).

3 UNCERTAINTY WITH FUZZY

Fuzzy numbers are useful for arithmetically managing imprecise numerical quantities and decision makers' subjective preferences in a variety of decision-making circumstances. Because of imprecision inherent in human decision-making, they are widely used in a variety of applications for handling practical challenges of many types in real-world contexts (Deng, 2014).

As a result, comparing and ranking fuzzy numbers becomes a significant challenge that must be answered sufficiently in decisions under uncertainty. It's difficult and time-consuming to compare and evaluate fuzzy numbers in order to determine their overall ranking in a specific context. This is due to the fact that in many practical scenarios, fuzzy numbers, as represented by the possibility distribution (membership functions), often overlap. It might be difficult to tell whether one fuzzy number is larger or smaller than another in a given setting, especially when the two fuzzy values are close (Deng, 2014).

One way to deal with uncertainty is using the three-point estimate (worst-case, most likely and best-case), as suggested by PMI (2021). The three estimated values indicate the direct use of triangular fuzzy numbers. A triangular fuzzy number A is one with the following membership function μ_A, graphically represented in Figure 1 (Wang, 2015):

$$\mu_A = \begin{cases} \frac{x-a_l}{a_m-a_r} & a_l \leqslant x \leqslant a_m \\ \frac{a_r-x}{a_r-a_m} & a_m \leqslant x \leqslant a_r \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

Wang (2015) concluded that two generic triangular fuzzy numbers, as presented in Figure 2, may be compared by a fuzzy preference relation P, with

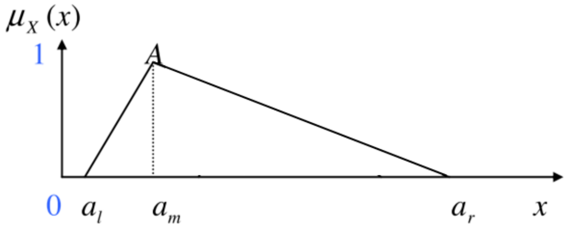

Figure 1: The membership function of triangular fuzzy number A - Adapted from (Wang, 2015).

membership function $\mu_P(A,B)$, representing preference degree of A over B. However, this comparison is complex in terms of time when dealing with k fuzzy numbers, due to pair-wise comparison. The proposal is, in a set of k triangular fuzzy numbers $S = \{X_1, X_2, ..., X_j\}$, compare $X_j = (x_{jl}, x_{jm}, x_{jr})$, $j = 1, 2, ..., k$, with the average $\bar{X} = (\bar{x}_l, \bar{x}_m, \bar{x}_r)$, as presented in Equation 9 (Wang, 2015):

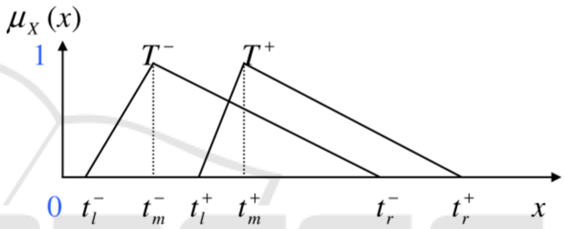

Figure 2: The membership functions of triangular fuzzy numbers T^+ and T^- (Wang, 2015).

$$\mu_{P^*}(X_j, \bar{X}) = \frac{1}{2}\left[\frac{(x_{jl} - \bar{x}_r) + 2(x_{jm} - -\bar{x}_m) + (x_{jr} - \bar{x}_l)}{2\|T_S\|}\right] \tag{9}$$

where:

if $t_{sr}^+ \geqslant t_{sr}^-$:

$\|T_s\| = \frac{(t_{sl}^+ - t_{sr}^-) + 2(t_{sm}^+ - t_{sm}^-) + t_{sr}^+ - t_{sl}^-}{2}$

if $t_{sr}^+ < t_{sr}^-$:

$\|T_s\| = \frac{(t_{sl}^+ - t_{sr}^-) + 2(t_{sm}^+ - t_{sm}^-) + t_{sr}^+ - t_{sl}^-}{2} + 2(t_{sr}^- - t_{sl}^+)$

$t_{sl}^+ = \max\{x_{jl}\}$

$t_{sm}^+ = \max\{x_{jm}\}$

$t_{sr}^+ = \max\{x_{jr}\}$

$t_{sl}^- = \min\{x_{jl}\}$

$t_{sm}^- = \min\{x_{jm}\}$

$t_{sr}^- = \min\{x_{jr}\}$

$j = 1, 2, ..., s$

At the end, one has s $\mu_{P^*}(X_k, \bar{X})$ values, representing preference degree of X_k over $\bar{X}$ in S (Wang, 2015). Allowing a proportional comparison among s triangular fuzzy numbers.

4 PROPOSED METHOD

The proposed method for this work indicates three steps for a final projects ranking, as presented in Figure 3.

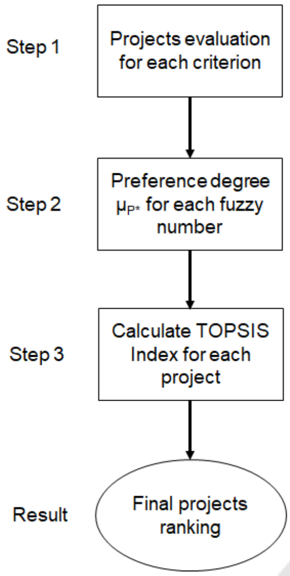

Figure 3: Proposed method flow.

At Step 1, for each selected criterion i ($i = 1,2,...,n$), the projects are evaluated by specialists. They receive values, in a predefined range (from 1 to 10, for instance), representing the relative importance of the project in the scenario. These values are established using three-point estimation. As a result in this step, each project has three estimated values for each criterion i, forming a triangular fuzzy number. That is, k ($j = 1,2,...,k$ representing each project) triangular fuzzy numbers for each criterion i.

Uncertainty in project ranking process is dealt in Step 2. For the n criteria, all k projects' fuzzy numbers are compared among each other, using Equation 9. It generates new values, representing the relative preference degree of project j related to the others, in the same criterion i.

In the last step (Step 3), TOPSIS method is applied, indicating the final projects' ranking, from the best option to the worst (based on the selection criteria). Decision-maker may choose the selected projects, to companies' portfolio for execution.

To better represent the importance of the criteria in the decision, they can be associated with weights, which will be considered when defining the ranking.

5 NUMERICAL EXAMPLE

The method proposed in Section 4 was applied over a set of 11 real R&D software development projects (the same set of Marcondes (2021)). All the projects were evaluated by three experts in market and software development. The criteria were the same used in Marcondes (2021).

- **C1 - Return/risk rate (weight - 0,4):** a ratio between the estimated return and the associated risk (from 1 - the lowest to 10 - the highest);
- **C2 - Competitiveness improvement (weight - 0,3):** the capacity of project for improving company competitiveness (from 1 - the lowest to 10 - the highest);
- **C3 - Market potential (weight - 0,2):** the capacity of project for improving market share or market insertion (from 1 - the lowest to 10 - the highest);
- **C4 - Degree of innovation (weight - 0,1):** how innovative the project is (from 1 - the lowest to 10 - the highest).

The final goal were the selection of three projects to be executed by the company, being the best placed in the final ranking. They would be the most aligned with the defined strategy.

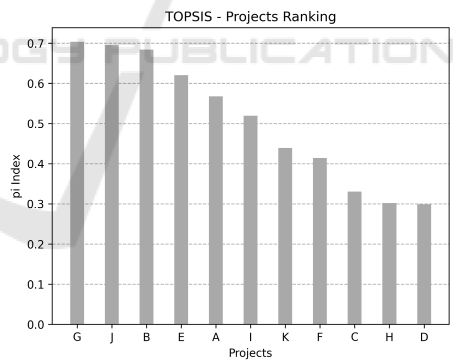

Figure 4: Projects Ranking - With Uncertainty - Fuzzy Approach.

The result obtained with the execution of the method was the selection of projects G, J and B, which were the ones that obtained the best position in the final ranking. Comparing this result with the selection presented in Marcondes (2021), it can be seen that the selected projects were the same considering the uncertainty scenario and using the Monte Carlo simulation. Considering the whole ranking, all the projects kept the same position.

Table 1: Projects Characteristics.

Project	Criteria											
	C1			C2			C3			C4		
	WC	ML	BC	WC	ML	BC	WC	ML	BC	WC	ML	BC
A	8	10	10	2	3	4	1	2	4	2	3	5
B	7	8	9	4	5	6	7	8	9	6	7	8
C	1	2	4	4	6	7	3	5	6	3	4	5
D	1	1	2	1	2	3	7	9	10	9	10	10
E	3	5	6	6	9	10	8	10	10	5	6	7
F	5	6	7	2	3	6	1	2	3	1	2	4
G	5	7	9	5	7	8	5	7	9	8	9	10
H	2	3	4	4	5	6	2	3	5	2	3	4
I	7	8	9	1	1	3	4	6	7	5	7	8
J	6	9	10	8	9	10	1	2	3	3	4	5
K	2	3	5	7	8	10	1	1	2	3	5	7

6 CONCLUSIONS

The selection of projects in companies is necessary, due to the scarcity of resources and difficulty in executing all the candidates that present themselves. Thus, using formal mechanisms for selecting projects for execution (project portfolio) is important for better application of resources, maintaining strategic objectives.

Since several factors must be taken into consideration simultaneously in the selection, the application of Multi-Criteria Decision Methods can be useful. Many of them allow ranking of options, comparing predefined criteria.

Like any process that involves decisions about future situations, uncertainty is present. The decision maker should consider it.

This work presents a way of selecting projects that uses the TOPSIS Multi-Criteria Decision Method. To address uncertainty, the proposal uses fuzzy triangular numbers and a means of comparing them.

The result was compared with that presented in a previous work, indicating the same subset of projects to be selected. This assessment should be made more broadly and considering other examples. But it indicates the coherence of the method used with the one that deals with uncertainty through the Monte Carlos simulation.

As future works, new experiments with other examples of project selection and the application of other multi-criteria decision methods can be considered, in addition to TOPSIS.

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