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Computational Tool Development: implementation and case study of the PROMETHEE I, II, and III methods

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Abstract The paper aims to present an alternative computational tool based on PROMETHEE family methods. Regarding the method, the steps that make up the axiomatic process and the first three extensions of the PROMETHEE method are exposed in detail. The software developed has the purpose to assist the decision maker in the method implementation in a given case, the tool presents a simple algorithm, where its own structure guides the decision maker step by step in the understanding and applying of the PROMETHEE method in a multicriterial problem. The software presents some new features, as the inclusion of PROMETHEE III in a computational tool, and a model of results analysis utilizing three methods simultaneously, by the same data input. A case study is presented to demonstrate the functioning of the tool and the analysis of the results generated by scripts and graphic models. The proposed tool proves to be effective and it can be applied in the academic field, as a form of aid in the learning of the PROMETHEE method with different ways of result analysis, or in organizations, assisting managers in their decision making. The simultaneous application of the three methods to the data in evaluation allows at the same time to make a sensitivity analysis comparing the suggestions.

Keywords: Decision-making, Multicriteria Decision Aiding, PROMETHEE, Computational tool, MCDA integration;

1 Introduction

Decision making is present in the daily lives of people and organizations, always being necessary for the establishment and development of future steps. Make a decision is always necessary when there is a problem that has more than one means to solve it. Even when there is only one choice for resolution, the decision maker has the alternative of taking action as a solution or not (GOMES; GOMES, 2019).

The Operational Research (OR) makes use of mathematical and logical models allowing solve real problems present in different areas of human activity (SANTOS *et al*., 2015). A significant characteristic of OR technics is that the solutions are not closed manner with only the application of a formula. Commonly these solutions are only made possible by the use of some algorithms.

Decision making can be classified into a choice, classification, ordering, ordered classification and prioritization. It is also classified as its number of criteria used for the analysis of alternatives, being related to monocriterion or multi-criteria. Multiple Criteria Decision Methods (MCDM) has specific characteristics, bringing the decision maker a new discussion: “Which alternative is more viable for certain situations or requirements?” (GOMES et al., 2013).

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MCDM plays an important role to select the non-dominate one(s) among several feasible alternatives evaluated according to multiple criteria (SOUZA et al, 2018). In a MCDM it is necessary that the modelling allows the subjectivity of the evaluation, where the fundamental problem of multicriteria analysis is the association the preference relations (subjectivity) between the criteria in the decision process (CARDOSO et al., 2009).

MCDM can be understood as techniques that enable the structuring and analysis of complex evaluation problems in a transparent manner, with the introduction of quantitative and qualitative criteria, in specific cases, with trade-offs between them. These methods allow organizations to structure a decision-making process, considering various aspects of evaluation, such as technical, socioeconomic and environmental at operational and strategic levels for decision making (GRECO; FIGUEIRA; EHRGOTT, 2016).

The applications present in MCDM have techniques that seek to make more assertive viable, solve problems through mathematical modelling, helping the decision maker in solving problems in which there may be goals to be met simultaneously. It is noteworthy that the methods present in the MCDM do not aim to present to the decision maker a definitive solution to solve the problem but to support the decision process meeting the requested constraints, within an analyzed context (ALMEIDA *et al*., 2015).

There are a large number of MCDM methods, so none designed to solve all kinds of decision problems, but rather to support the decision maker in a specific problem (WATRÓBSKI and JANKOWSKI, 2015). Among the many methods of multicriteria analysis present in the academic field, the main ones are the methods of the American (compensatory) and French (non-compensatory) schools. In the first case there is the AHP (Analytic Hierarchy Process), MAUT (Multi-attribute Utility Theory and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution). Related to the French school are the family of methods ELECTRE (Elimination and Choice Expressing Reality) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations), operating in the ranking, classification, and selection of alternatives.

Application of information systems enables companies to make better decisions on a day-by-day basis, supporting the process evaluation and allowing the organizations having a better view of the problem (ISHIKIRIYAMA; MIRO; GOMES, 2015). Technological support allows a better decision analysis and the use of information systems enables generating knowledge to innovation and problem-solving (PEREIRA *et al*., 2015).

Computational tools become facilitators for multicriteria decision analysis. Because they are complex mathematical models, the technological support enables the decision maker to implement the AMD methods, once the user has enough to understand their problem and have knowledge of the data to be requested throughout the decision process (ISHIZAKA; NEMERY, 2013).

1.1 Questions and Objectives

The paper aims to present a new computational tool based on three variants of PROMETHEE family methods, all the process is made in an integrated way with the three different evaluation formats. The implementation of a methodology that simultaneously uses the three methods, based on the data of the decision maker, will allow the decision maker to make a sensitivity analysis comparing the results, providing greater security for the final decision.

After the introduction of the study, section 2 will expose the concepts, available software, and the axiomatic structure of PROMETHEE I, II, and III methods. Section 3 is intended for the presentation of the proposal alternative software based on the method along with a demonstration of implementation by a case study. Section 4 concludes the research findings indicating the main gains of the platform.

2 PROMETHEE method

The multicriteria methods of the PROMETHEE family, proposed by Brans, Vincke, and Mareschal (1984), aims to construct a valued outranking relation in decision problems (BRANS and SMET, 2016). For Brans, Vincke and Mareschal (1986), state that the main characteristic of the PROMETHEE method is simplicity, clarity, and stability, where the notion of a generalized criterion is used to construct the outranking. The method establishes a preference structure between the alternatives, having a preference function for each criterion (BRANS; MARESCHAL, 2005).

In the literature, the first three variants of the modelling are: PROMETHEE I – Partial pre-ordering, resulting of a possible incomparability relation between the alternatives; PROMETHEE II – Total pre-ordering between alternatives, intended to outranking analysis; PROMETHEE III - complete pre-ordering, with amplification of the notion of indifference.

2.1 *PROMETHEE software*

In search of expanding applications, enabling a trivial implementation of the methods to a given case, and consolidate the modelling, researchers and companies have been developing a significant amount of MCDM software, allowing users to structure, evaluate and obtain a favorable solution to their decision problems (ISHIZAKA; NEMERY, 2013).

In the past years it was developed some computational platforms related to the method. PROMETHEE observes preferences and computes them in the software; illustrations support the results to obtain a better perspective of all the preferences, for example, if a cluster is formed by the alternatives e.g. (GAIA, 1990).

As present Brans and Smet (2016), in 2010 it was released the third generation of PROMETHEE based software, named D-SIGHT, which has preceded by DECISION LAB and PROMCALC platforms. The software is based on visual interactive tools, assisting the decision maker in the implementation of PROMETHEE I and PROMETHEE II methods and enabling a group evaluation as well.

2.2 *PROMETHEE functionality*

Considering A, a set of alternatives, for each ai ∈ A, i = 1, ... n, f_j (a_i) will be an evaluation of that alternative according to the criterion j, j = 1, ... k. Comparing the alternatives a_1 and a_2 of set A, the function $\boldsymbol{P_j(a_1, a_2) = P(x) = P[f(a_1) - f(a_2)]}$ represents the degree of preference of a1 in relation to a2 according to the criterion j. When the criterion needs to be maximized, uses $x= f(a_1)-f(a_2)$ to define a preference function. If it is necessary to minimize the criterion, $x= f(a_2)-f(a_1)$ is used as preference function.

Six types of preference functions have been proposed to normalize the values obtained from the differences between the alternatives. The functions have parameters strict preference (P) and indifference (q). For more detail about the application, please consult (Brans *et al*., 1986).

2.3 *PROMETHEE I*

Using the positive outranking flows (1), characterized by the dominance level of a_1 over all other alternatives of the set, and the negative outranking flows (2), representing the dominance level of all alternatives over a_1, it is possible to obtain a partial pre-ordering evaluation, where:

$$\Phi^+(a_1) = \frac{1}{n-1}.\sum_{x\in A}^{n} \pi(a_1, x) \tag{1}$$

$$\Phi^-(a_1) = \frac{1}{n-1}.\sum_{x\in A}^{n} \pi(x, a_1) \tag{2}$$

- a_1 is preferable to a_2 ($a_1 P a_2$) if $\begin{cases} \Phi^+(a_1) > \Phi^+(a_2) \text{ and } \Phi^-(a_1) < \Phi^-(a_2) \\ \Phi^+(a_1) = \Phi^+(a_2) \text{ and } \Phi^-(a_1) < \Phi^-(a_2) \\ \Phi^+(a_1) > \Phi^+(a_2) \text{ and } \Phi^-(a_1) = \Phi^-(a_2) \end{cases}$
- a_1 is indifferent to a_2 ($a_1 I a_2$) if $\Phi^+(a_1) = \Phi^+(a_2) \text{ and } \Phi^-(a_1) = \Phi^-(a_2)$

- a_1 is incompatible to a_2 ($a_1 R a_2$) if $\begin{cases} \Phi^+(a_1) > \Phi^+(a_2) \text{ and } \Phi^-(a_1) > \Phi^-(a_2) \\ \Phi^+(a_1) < \Phi^+(a_2) \text{ and } \Phi^-(a_1) < \Phi^-(a_2) \end{cases}$

2.4 PROMETHEE II

The second variant of the method consists of the using of preference (*P*) and indifference (*I*) relations, utilizing the net outranking flows obtained by the equation (3), enabling a total pre-ordering evaluation.

$$\Phi(a_1) = \Phi^+(a_1) - \Phi^-(a_1) \quad (3)$$

- a_1 is preferable to a_2 ($a_1 P a_2$) if $\Phi(a_1) > \Phi(a_2)$
- a_1 is indifferent to a_2 ($a_1 I a_2$) if $\Phi(a_1) = \Phi(a_2)$

2.5 PROMETHEE III

As presented by Tzeng e Huang (2011), based on the ratios of PROMETHEE methods I and II, the third method associates for each alternative an interval *[x(a₁), y(a₁)]*, defining a total pre-ordering of intervals (4).

$$\begin{cases} x_{a_1} = \overline{\Phi}(a_1) - \alpha\sigma_{a_1} \\ y_{a_1} = \overline{\Phi}(a_1) + \alpha\sigma_{a_1} \end{cases} \quad (4)$$

- a_1 is preferable to a_2 ($a_1 P a_2$) if $x_{a_1} > y_{a_2}$
- a_1 is indifferent to a_2 ($a_1 I a_2$) if $x_{a_1} \leq y_{a_2}$ and $x_{a_2} \leq y_{a_1}$

3 Software PROMETHEE_I_II_III

The proposed tool was developed in Python 3.7, due to the flexibility offered by the language, enabling a clear and organized algorithm. The code has a simple structure for the user, guiding the decision maker in the steps of entering data presents in the axiomatic structure of PROMETHEE methods.

The present software does not intend to replace the existing computational tools based on PROMETHEE, although the new application brings gains for a decision assessment, such as the addition of the PROMETHEEE III method in the evaluation and the integrated assessment of the three methods in a single software, generating a sensitivity analysis to the decision maker. The proposed platform shows other perspective to develop the coverage of PROMETHEE method, supporting scientific studies, business issues; according to elapsing of technology development.

3.1 Case Study and Software Application

As an example of application of the new platform, it is presented a case study regarding the choice of an Enterprise Resource Planning (ERP) software. In the scenario of the case (table 1), are analyzed five alternatives under four criteria. The price criterion is represented by the respective values to the acquisition of each software, the values are in thousands of dollars and this criterion must be minimized. The values of complexity are registered in a range from 1 to 10, as lower is the value, less complex is the software and it must be minimized. The security of each software is evaluated in a range from 1 to 4, as higher the value, more reliable will be, this criterion must be maximized. The last criterion is the performance, the values are respective to the number of transactions per hour allowed in each ERP and must be maximized.

Table 1. Evaluation Matrix

Criteria	SARP	ORAC	TOTS	MICRO	IBRP	*function*
Price	15	29	38	24	25.5	min
Complexity	7.5	9	8.5	8	7	min
Security	1	2	4	3	3	max
Performance	50	110	90	75	85	max

In the first step, is required to the user the number of alternatives and criteria that will be evaluated, and the names of each one. Following the procedure, it is necessary for the user defines which criterion must be maximized or minimized. Following this logic, for each criterion, the decision maker should specify the function, typing "max" to maximization function or "min" to minimization. After specifying the comparison functions, it is shown a matrix (Alternative x Alternative) to each criterion. The matrices are exposed to the resulting comparison between each pair of alternatives as presented in figure 1.

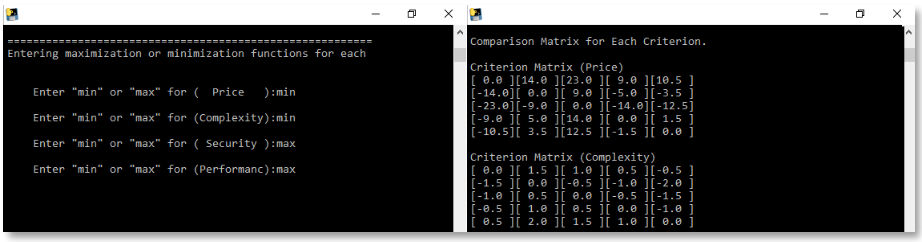

Fig. 1. Comparative evaluation between alternatives (Software PROMETHEE_I_II_III)

The next step is intended to obtain the values normalized. Each function has its respective characteristics and evaluation parameters. In the given case, for all criteria it was utilized the linear function V-SHAPE I, defining the parameters of indifference (q) and preference (p), as follows: price, q= 2 and p = 5; Complexity, q=0.5 and p = 1; Security, q=1 e p=2; performance, q=10 and p=20. Regarding this step, the system shows the six preference functions of the PROMETHEE method, along with the parameters that will be requested. Figure 2 exposes the interface to set the types of function along with the normalized matrices.

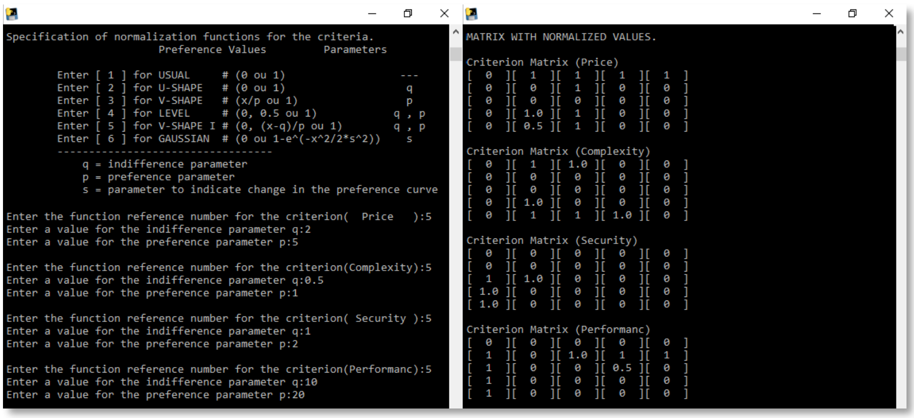

Fig. 2. Normalization of alternatives (Software PROMETHEE_I_II_III)

The following step (figure 3) is intended to the setting of weights to the normalized values if it is the same importance to all criteria, only is necessary type "i", otherwise type "p" to set the weighted values. For each criterion is requested a value that must be between 0.01 and 1.

With all data entered, the system shows a matrix with the averages of the values obtained after the application of the weights. Following the method, by these values, will be obtained the positive, negative and net outranking flows to each alternative in the set of evaluation as is presented in figure 3.

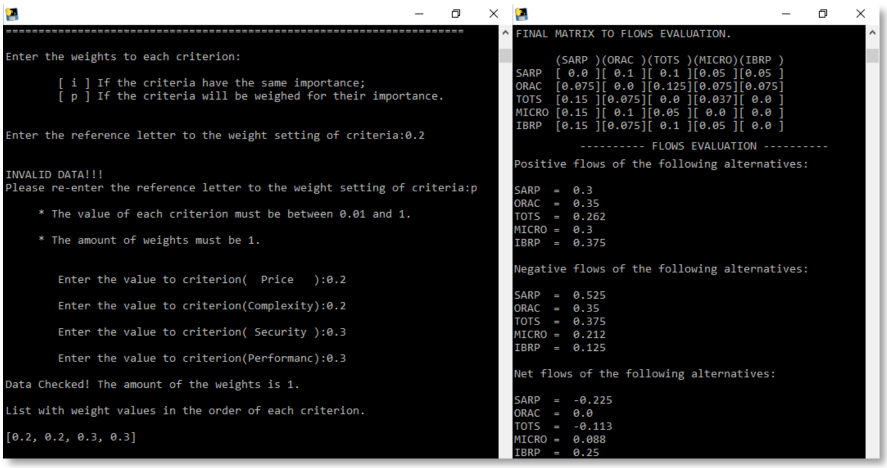

Fig. 3. Weights and Flows (Software PROMETHEE_I_II_III).

The PROMETHEE I method is obtained by the positive and negative outranking flows. In the software, for each alternative, it is presented a preference relation of this one as the other from the set (figure 4). In the given case it is possible to recognize that the alternative with the best performance is the IBRP software, obtaining a total preference as the other alternatives. In the evaluation, the SARP alternative obtained the worst performance, being classified as not preferable regarding all alternatives from the set.

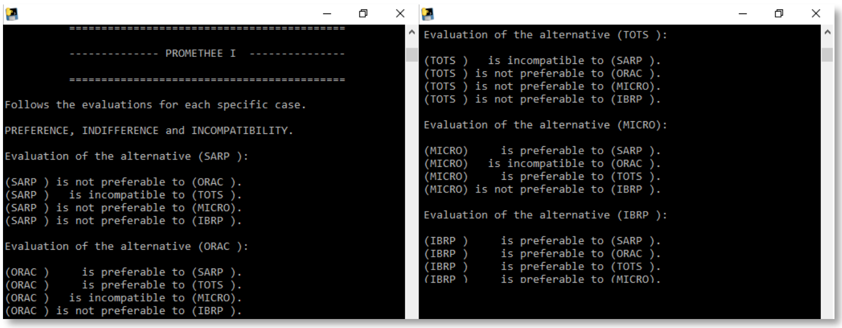

Fig. 4. Evaluation PROMETHEE I (Software PROMETHEE_I_II_III)

The analysis of PROMETHEE II, it is enabled by the net outranking flows to each alternative. The result is displayed following the logic of the method, ordering from the more favorable alternative to the less favorable to be selected. In this evaluation is possible to recognize that the alternative IBRP keeps obtaining the best performance, presenting the result of greater net flow, as it is possible to see in figure 5.

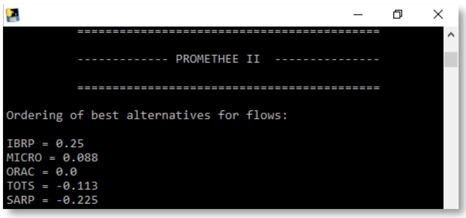

Fig. 5. Evaluation PROMETHEE II (Software PROMETHEE_I_II_III)

The PROMETHEE III evaluation is the third analysis format of the software. Using the sample of net flows in the respective case, it was obtained a standard error of 0.082, generating the lower (x) and upper (y) limits for each alternative. As presented in figure 6 for each alternative is presented it preference relation regarding other options from the set. In the previous evaluation, the IBRP outranked the MICRO, however, utilizing the evaluation by intervals, both options became indifferent, as they presented a cross between their intervals. Although, due to the non-transitivity rule between the particular relationships, the IBRP remains preferable to SARP, ORAC and TOTS.

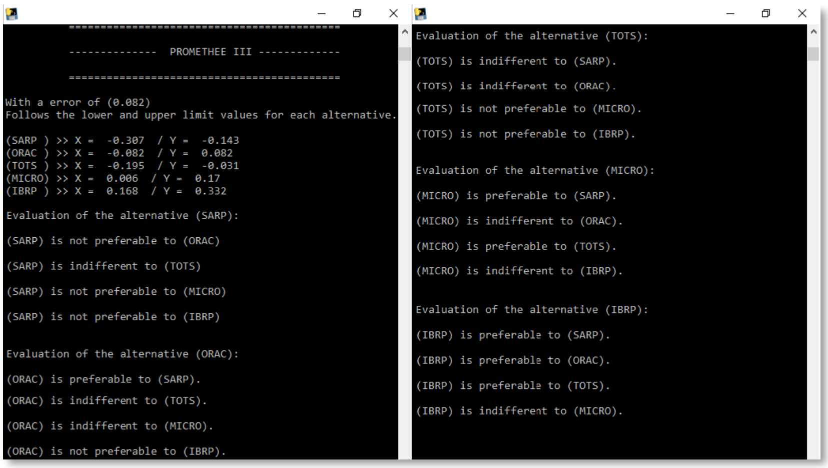

Fig. 6. Evaluation PROMETHEE III (Software PROMETHEE_I_II_III)

In the search for bringing a robust analysis, the proposed algorithm enables a graphical analysis of the result (figure 7). The charts displayed were adapted by the Matplotlib library, exclusive from python. The library allows adapting simple chart models, as a line chart, to a graphical analysis that represents the partial and total pre-ordering from PROMETHEE methods.

The presentation of three graphics displaying the results in different models of evaluation enables the decision maker to has a sensitivity analysis of the case, by the moment that it is possible to have an evaluation of three forms, respective to each method, simultaneously. The image of charts generated by the software can be saved in the user's device for future analysis.

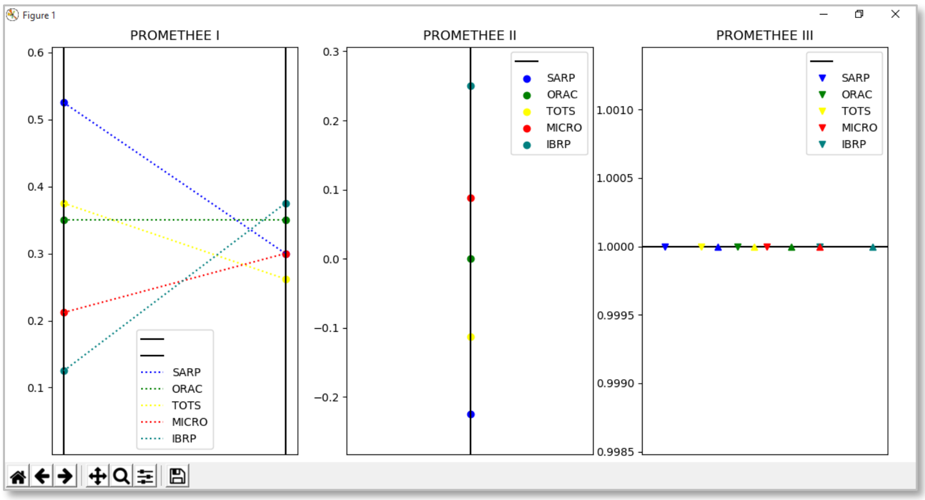

Fig. 7. Evaluations charts (Software PROMETHEE_I_II_III)

In this model of analysis, the representation of results is clearer. In the first chart is possible to recognize that the alternative IBRP has the largest positive outranking flow and the smallest negative flow, by the moment that it line crosses all lines respective to each alternative from the set. In the second chart, PROMETHEE II, it is simpler to analyze, only verifying how higher is the alternative position, the better performance it represents. Regarding the last evaluation, it is clearer the representation of lower and upper limits of each alternative, enabling to evaluate how better each ERP software is rated regarding the other from the set.

The software can be downloaded by the link: https://lableggo.org/softwares/

4 Conclusion

The present paper presents an alternative software based on the MCDM PROMETHEE I, II, and III. Exploring the concepts of multicriteria analysis, it is approached the particularities that compose the evaluation and some methods, along with their characteristics but emphasizing the PROMETHEE methods.

To gain a better understanding of the method, the paper explored all steps that constitute the axiomatic structure of the PROMETHEE methods, from the data entry to results analysis. In the work was approach the variants I, II, and III from the original modelling, exploring the different forms of analysis and the manipulation of outranking flows, characteristics to each extension.

The computational tool presented was developed to support a decision maker in the application of the PROMETHEE method in a given case. Regarding other software based on the modelling, the new platform presents some increases for a multicriterial evaluation, as the inclusion of a third evaluation format based in the PROMETHEE III method; the presentation of results provided in each stage, recognizing the criteria of greatest influence and which are the best alternatives in each specific criterion; and a format of analysis with three methods simultaneously, utilizing the same data set, enabling a robust and sensitivity analysis to the case by scripts and graphical models, how it is exposed in the case study presented in section 4.

The software proposed has a simple framework, even if a user has no familiarity with the method, it is possible to use. The tool guides the user into all steps of the method, explaining which kind of data it is necessary to enter in each evaluation step. The format used to construct the algorithm brings gain to the academic field, by the moment that the software can be used to teach the method, no just presenting a table for data entry and given a result, but exploring all steps that structure the PROMETHEE method, making the user recognize how each importance flow is generated and its manipulation by the three evaluation formats influence the results.

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