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Criteria in AHP: a Systematic Review of Literature

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Abstract

The Analytic Hierarchy Process (AHP) is widely used by decision makers and researchers. The definition of criteria and the calculation of their weight are central in this method to assess the alternatives. However, there are few studies that focus on them. The purpose of this study is to develop a systematic review of literature on the real cases that applied AHP to evaluate how the criteria are being defined and measured. In the 33 cases selected, they mainly used literature to build the criteria and AHP or Fuzzy AHP to calculate their weight, while other techniques were used to evaluate alternatives.

1. Introduction

The Analytic Hierarchy Process (AHP) is a method of "measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales" [1]. It has been one of the most widely used multiple criteria decision-making tools." [2]. It is used by decision makers and researchers, because it is a simple and powerful tool [3]. Thomas L. Saaty built this method seeking a systematic practice to define priorities and support complex decision making [3]. In fact, the hierarchical structure of AHP methodology is able to measure and synthetize a variety of factors of a complex decision making process in a hierarchical manner, making it simple to combine the parts in a whole. A bibliometric research [4] found that the number of publications related to MCDM – Multicriteria Decision Making /MAUT – Multiattibute Utility Theory increased 4.2 times, from 1992 to 2006. This phenomenon can be mostly attributed to a relevant growth of the publications focused on AHP and EMO – Evolutionary Multi-objective Optimization.

Thus, the three main AHP methodology functions are: structuring complexity, measurement, and synthesis [3]. For the first function, Saaty sustains that to deal with the complexity of a decision making process we need

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to identify all the different factors that affect the decision and organize them in a hierarchical structure of "homogenous clusters of factors" [3]. The measurement in ratio scale is obtained comparing those factors in pairs. The weight of each factor in the hierarchy will be found in a process where each factor is compared with its parent factor. The priorities (weights) throughout the hierarchy will be found by multiplying the priority of one factor in each level for the priority of the factor with which the first is linked (parent factor). Although AHP has analytic in its name, because it separates the abstract entity into its constituent elements, the method is important because of its "ability to measure and synthesize the multitude of factors in a hierarchy" [3].

Many studies have been written about how to use the method [1,2,3,4], some about especific aspects of the method [5,6] but this article aims to assess how the AHP method is being applied in the practice and, particularly, how the criteria are being defined and measured. For this propose will be developed a systematic review of literature on the real cases that applied AHP. The following section of the article briefly describes the method of AHP. The sections following comment on the methodology used and finally the analysis of the articles will be discussed.

2. Analytic Hierarchy Process (AHP)

To make a good decision, the decision maker must know and define: the problem, the need and purpose of the decision, the criteria and sub criteria to evaluate the alternatives, the alternative actions to take, and stakeholders and groups affected [1]. These criteria and sub criteria can be tangible or intangible; when the criteria are intangible, there is no way to measure them as a guide to the ranking of the alternatives. Creating priorities for the criteria themselves in order to weigh the priorities of the alternatives and add up all the criteria to obtain the desired overall ranks of the alternatives is a challenging task [1]. There are six phases in this method [1,7]:

- **Define the problem and determine the kind of knowledge sought.** The problem to be analyzed is chosen from all those considered important or complex enough to be analyzed. This choice might be itself a complex problem for which a specific analysis is required [7]. In defining and selecting a problem it is important to make explicit all the assumptions and the perspective by which this decision has been taken.
- **Structure the decision hierarchy.** This structure is built "from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria) to the lowest level (which is usually a set of the alternatives)." [1] Conceptually, once the main objective or goal is defined, we can access a correlated problem seeking a solution either through a top-down process (from criteria to alternatives) or through a bottom-up process (from the alternatives to the criteria). It is necessary to build a model in such a way that the criteria and the alternatives that are really relevant can be identified. The decision hierarchy must be extensive enough to include the main concerns of the decision makers and small enough to allow timely changes. In this step, the decision makers must eliminate the alternatives considered impracticable or that do not match the criteria considered really relevant [7].
- **Construct matrices to calculate a set of pairwise comparison.** "Each element in an upper level is used to compare the elements in the level immediately below with respect to it." [1] This means that one matrix must be built for each criterion in the upper level. The comparison is made through a scale to show "how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared" [1]. A verbal scale is used for the measurement of quantitative as well as qualitative criteria. The scale ranges from "equal" (number 1) to "absolutely more important than" (number 9). The preferred criterion cell of the matrix has the value and the other has the inverted value (1 / value). The redundancy of those comparisons in pairs helps in making the analysis more precise and in building knowledge about the elements of a problem. The superiority of this method lies exactly in its capacity to attribute a relative weight to all the elements of a problem, either tangible or not, and to build a hierarchy of their relative relevance.

- **Calculate the relative weight of the elements to each level** through these steps: (i) add the value of the columns to normalize the matrix; (ii) in the normalized matrix, sum up the lines to obtain the relative priority of the criteria; (iii) evaluate the consistency of the matrix, by calculating the eigenvalues to compare with the random consistency according as matrix size. If there is a consistency problem, the decision maker must review his/her comparisons to improve them; (iv) for each criterion, the anterior steps must be done; (v) calculate values of each alternative for each criterion are included in one matrix, with the application of calculated priority; (vi) add the values of each alternative to obtain the final value. The best alternative is the one with the highest value (priority) [7].
- **Check and balance of decision.** This phase is necessary to check if the results of the application of AHP are compatible with the expectations and if flaws are identified, a review of the previous process is needed. It is very important to avoid gaps between the model and expectations. Whenever necessary, the model needs to be complemented to include elements or criteria not previously identified or considered.
- **Decision documentation.** To document the decision making process it is important to record all the reasons that supported how and why the decision was made. These records can be helpful to justify the process to third parties or to reflect on it in the future, allowing a continuous improvement of the decision making process.

3. Methodology

This paper uses a descriptive approach with the aim of increasing knowledge about the AHP method and to make clear how criteria are managed through this method. Based on this, a systematic literature review was used as a research strategy because it is an evidence-based practice [8] which obtains different answers to the research question and identifies which of them are revealed to be more efficient. Eleven steps were used as defined by [8] and are detailed in Figure 1:

1. The definition of the research question, how criteria are being defined and measured in AHP method:
2. The committee consisted of two researchers, one an expert in the AHP method and the other in project management;

Initial Definition
- Step 1 Define the question
- Step 2 Committee Definition
- Step 3 Write a Protocol

52 articles founded

5 articles rejected reading abstract: 4 not real case, 1 not MCDM -> 49 articles was selected

Research
- Step 4: Carry out the literature search
- Step 5: Screen the references
- Step 6: Assess the remaining studies
- Step 7: Data extraction

14 articles rejected:: 8 not real case, 1 same case, 1 case not clear, 1 not MCDM, 3 not use AHP adequately -> 33 articles was selected

Assessment
- Step 8. Critical appraisal
- Step 9. Synthesis of the studies
- Step 10 Consider the effects of bias
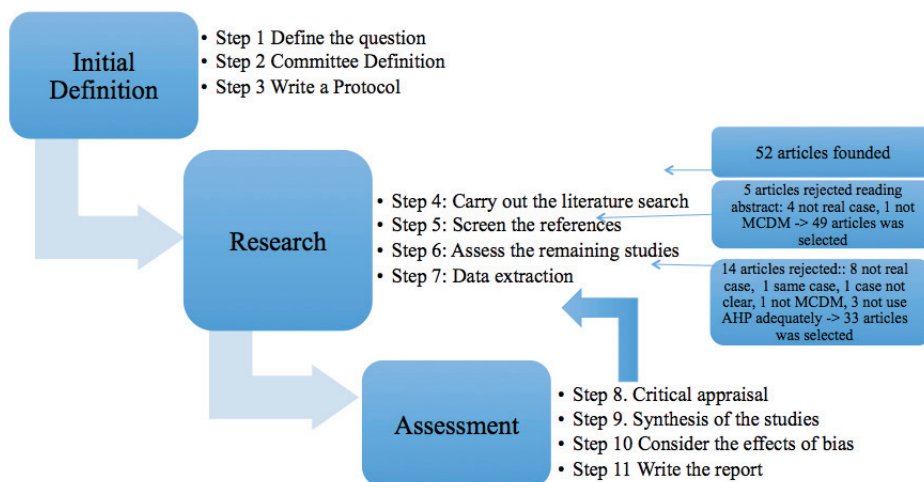- Step 11 Write the report

Fig. 1. Systemic review development flow

3. The protocol for research consisted of: tools to access information (Science Direct); words to be researched ("AHP" in the title and "criteria" in the title, abstract or keywords); scope areas (Business, Management and Accounting); the article should contain a real case study, not an example; refer to multi-criteria decision-making (MCDM); and should have been published in the last ten years;

4. In researching the literature, 52 articles mentioned the researched words and scope areas;

5. After screening the articles' abstracts, 5 articles were rejected, because four of them were not based on real cases and one did not use MCDM;

6. After evaluating the studies, a further 14 articles were rejected: seven were not based on real cases; one used the same case study referred to in another article; in one it was not clear if it was based on a real case; one was not based on MCDM; and finally, three were rejected because they did not use the AHP method adequately, (one used a Likert scale instead of pairwise comparison);

7. The first cycle of data extraction included: the referred to journal, the year of journal publication, the subject of the study (industry, function or system), the type of problem studied, the purpose of the article, the source of the criteria, the number of criteria layers, the number of criteria and sub criteria used, the number of alternatives, the participants in AHP, the type of comparison, the phases of the AHP method applied;

8. When critically reviewing the primary studies, we needed more information, thus other variables were necessary: if some alternatives were eliminated before AHP application; if another method was used and what it was; and if the final result of AHP application was reevaluated;

9. The synthesis of the cases selected was complemented by literature to support the conclusions;

10.   Evaluation of the limitations and biases of the studies;

11.   A final report was written.

4. Analysis

4.1. Selected Articles

33 articles were selected as shown in table 1. The object of all of these articles was the evaluation of specific real cases where the AHP method was adopted. All the articles refer to a case study. With the exception of seven all the articles were extracted from the Expert System with Applications Journal, The articles selected were published from 2005 through 2015 and the years that have more the one article are 2008 (5), 2009 (4), 2010 (5), 2011 (7), and 2012 (6).

Table 1. References selected in systematic review of literature

Id	Journal	Year	Problem type	Industry, function or system	Criteria source	Scale	Group judgment	Technique used
[9]	1	2005	Selection	IIT Industry	Organizational team and experts	AHP (9)	AIP#	AHP
[10]	2	2006	Selection	Public Administration	Organizational team	AHP (9)	AIJ	AHP
[11]	1	2008	Selection	Manufacturing industry	Organizational team	Fuzzy (5)	AIP#	FAHP
[12]	1	2009	Selection	Defense Industry	External expert team	AHP (9)	AIP#	AHP - TOPSIS
[13]	1	2009	Selection	Shipping industry	Literature	Fuzzy (5)	AIJ	FAHP
[14]	1	2009	Selection	Textile Industry	Organizational team and literature	Fuzzy (5)	AIJ#	FAHP
[15]	1	2010	Selection	Oil Industry	Organizational team	AHP (9)	AIJ#	AHP - FTOPSIS
[16]	1	2011	Selection	Textile Industry	Literature	AHP (9)	AIJ#	AHP - GRA

Id	Journal	Year	Problem type	Industry, function or system	Criteria source	Scale	Group judgment	Technique used
[17]	1	2011	Selection	Washing Machine industry	Organizational team and literature	Fuzzy (5)	AIP	FAHP
[18]	1	2011	Selection	Public Administration	Organizational team	Fuzzy (9)	AIJ	FAHP - VIKOR
[19]	1	2012	Selection	Public Administration	Literature and experts	Fuzzy (5)	AIJ#	FAHP
[20]	1	2012	Selection	Electronics industry	Organizational team	Fuzzy (9)	QFD (HOQ)	QFD-FAHP
[21]	1	2012	Selection	Shipping industry	External Expert team	Fuzzy (5)	AIJ	FAHP
[22]	1	2014	Selection	Airline industry	Literature	Fuzzy (9)	AIP#	FAHP
[23]	5	2007	Ranking	Manufacturing industry	Organizational team	Fuzzy#	AIJ#	FAHP
[24]	1	2008	Ranking	Electronics industry	External expert team	Fuzzy (9)	AIP#	FAHP
[25]	1	2010	Ranking	Electronics industry	Organizational team and experts	Fuzzy (9)	AIJ#	FAHP - Max-Min
[26]	1	2010	Ranking	Electronics industry	External expert team	Fuzzy (9)	AIP	FAHP - FTOPSIS
[27]	1	2011	Ranking	Education	Literature and experts	AHP (9)	AIJ	AHP
[28]	1	2011	Ranking	Public Administration	Literature	Fuzzy (9)	AIJ#	FAHP - ELECTRE
[29]	1	2012	Ranking	Healthcare Industry	Literature	Fuzzy (5)	AIJ#	FAHP - FTOPSIS
[30]	3	2012	Ranking	Telecommunications	Organizational indicators	AHP (9)	AIJ#	AHP
[31]	4	2012	Ranking	Education	Literature and experts	Fuzzy (5)	AIJ#	FAHP - COPRAS
[32]	5	2008	Ranking indicators	Education	Organizational team	AHP (5)	AIJ e AIP	AHP
[33]	5	2008	Ranking indicators	Public Administration	Literature and experts	Fuzzy#	AIP	FAHP
[34]	1	2008	Ranking indicators	Manufacturing industry	Literature and experts	Fuzzy (9)	AIP	FAHP
[35]	1	2009	Ranking indicators	Electronics industry	Literature	AHP (9)	AIP#	ANP-AHP
[36]	1	2010	Ranking indicators	Oil Industry	Literature and experts	Fuzzy (9)	SAM	FAHP
[37]	1	2010	Ranking indicators	Entertainment Industry	Literature and experts	Fuzzy (5)	AM	FAHP
[38]	1	2011	Ranking indicators	Entertainment Industry	Literature and experts	AHP (5)	AIJ#	AHP
[39]	1	2011	Ranking indicators	Manufacturing industry	Literature	Fuzzy (9)	AIP#	AHP and FAHP and FTOPSIS
[40]	1	2013	Ranking indicators	ICT industry	Literature	Fuzzy (6)	AIJ#	FAHP
[41]	6	2015	Ranking indicators	Healthcare Industry	Literature	AHP (9)	AIJ#	AHP

NOTE: Journal 1 is Expert Syst Appl, 2 is Int J Proj Mang, 3 is J Bus Res, 4 is Socioecon Plann Sci, 5 is Omega, 6 is Saf Sci.

NOTE2: The symbol # means that the process of judgment is not explicit in the article.

4.2. Define the problem and determine the kind of knowledge sought

As shown in Table 1, the cases studies related mainly to industries, and they present a wide variety of problems and criteria. The origin of the problems is not reported, nor was the kind of knowledge sought determined. For the most part, the articles focus on the importance of the context and how to treat the problem, offering detailed information about the methods and the mathematics involved. It is possible to assume that this approach was influenced by the scope of the Journal (Expert systems with applications). As far as the objective of the articles (problem type column in Table 1) is concerned, eight selected an alternative, five aim at how to rank alternatives and three seek how to rank indicators.

4.3. Structure the decision hierarchy

In general, the influence factors were denominated criteria. However, they also were called aspects [33,36] attributes [36], classes [22], dimension [35,39], families [38], index [30], and perspectives [33]. In most of the cases (17), as can be seen in table 1, the process to select the source of criteria was based on the literature; in another relevant number of cases (12) the process was based on selecting the criteria considered relevant for the organization. Only in four cases was the source to select the criteria supported by external specialist contribution.

It was suggested [7] that enviable criteria and alternatives be eliminated before applying the AHP method. However, only two cases [14,22] previously analyzed the alternatives to assess compliance with specific criteria: the screening method was used through 6 variables [22], which eliminated 7 suppliers from 10 analyzed; in another case [14] five out of eight alternatives were eliminated due to not meeting the criteria set by the organization. Only 3 articles analyzed previously criteria, in one [41] the number of 109 decreased to 20; in another [30], the criteria diminished from 60 to 44; and in another [35], the criteria diminished 5 from 17.

Saaty [1] affirms that to create priorities the following is needed: "for the criteria in terms of a higher goal, or if they depend on the alternatives, then in terms of the alternatives themselves." Thus, since the analysis of a problem involves a selection or a ranking of the possible alternatives, it would be reasonable that the criteria should be defined based on the alternatives. In the 14 cases of selection problem, only three cases were grounded in the literature [17,20,26], in the others there was the participation of organization decision makers. To rank the alternatives, the main source was the literature (four cases), followed by experts (two cases). Regarding the ranking indicators, the literature was, once more, the main source. However, the experts reviewed the criteria in many cases, as in [35] and [38], in which the Delphi technic was used, and in one case [32] the organizational team provided criteria.

To serve both consistency and redundancy to the AHP method, it is best to keep the number of criteria and alternatives at seven or less [42]. This suggestion was adopted in the vast majority of the cases reported, as can be seen in the item a in Fig.1, in accordance with the size pattern of the structure. The hierarchical structure in the cases reported has one to three layers. The dominant is the two-level structure. In three cases [11,12,15] a three-level structure was reported and in one case [22] a one-level structure was adopted.

The first layer of a hierarchical structure is the objective or goal to solve the problem. In the second layer of criteria, a minimum of 2 and a maximum of 20 criteria were observed (the latter number is not recommended because it would make pairwise comparison difficult). The average was 4.76 criteria and the mode 3 criteria. The third layer has two to ten sub criteria; the average is around five and the mode is five. The imbalance among the number of sub criteria, such as when one criterion has three sub criteria and one criterion has none, can happen but it is not common in the cases analyzed.

With the exception of eight cases [32–37,39,41] where no alternatives were reported due to the fact that the objective of the process was to identify and evaluate indicators, a maximum of 177 alternatives, an average of

11 and a mode of 3 were observed. Item b in Fig.1 was built to represent a standard of a hierarchical structure and the mode value for the layers, criteria, sub criteria and alternatives of the structure.
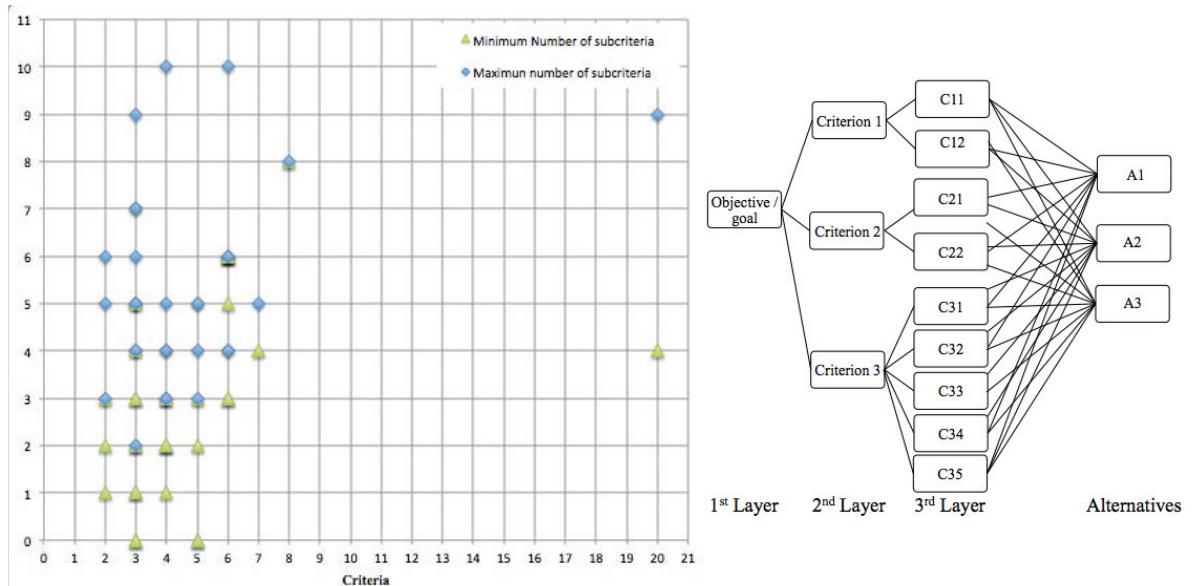

Fig 1 – a) average of structure quantity and b) standard of a hierarchical structure

4.4. Construct matrices to calculate a set of pairwise comparison and calculate the relative weight of the elements to each level.

There are mainly two ways to develop a group judgment [1,6], as can be seen in Table 1: the group wants to act together as a unit or as separate individuals. In the first situation we use the aggregation of individual judgment (AIJ) method: the group identity and decision is built while the individual identity is lost during each pairwise judgment. In the second situation, the aggregation of individual priorities (AIP) method is appropriate when the group members want to combine or aggregate not their judgments but only the final results [6], as happens in the specialist assessment process. The majority of the analyzed cases utilized the AIJ method to calculate the criteria weight, with the exception of 9 articles that adopted the AIP method. Few used another technique, such as quality function deployment (QFD) [20], approximation method (AM) [37], and similarity aggregation method (SAM), which measures the degree of agreement between experts according to a similarity measure function [36].

For those that used AHP, two ways to evaluate the alternatives were observed: rating, also called absolute judgment [4], for the analysis of quantitative criteria and pairwise or relative judgment [4], for the analysis of qualitative criteria. Only one case [21] use both ways to evaluate criteria. Although the methods are different, they offer similar results. However the pairwise method is more accurate, because of its process of comparative selection through pairwise comparisons. On the other hand, the rating method can be considered a more efficient method in a situation where many alternatives [1] are available, but the method requires a pre-defined and validated rating scale. Some it is not clear, as in [16,29], but pairwise was probably used.

Although AHP uses the same techniques to calculate weights for criteria and for alternatives, in the analyzed cases, while AHP or FAHP were predominantly used to evaluate criteria, different other techniques were used to evaluate alternatives, as can be seen in Table 1. This happened because the AHP method is flexible enough

to be integrated with different techniques [2]. AHP was the only method used in 7 articles and Fuzzy Logic AHP (FAHP) in 14 articles; one used both plus TOPSIS [39] to compare the results. Regarding FAHP, Saaty [43] said that consistency ratio (CR) of the pairwise comparison matrix is a measure used in AHP to improve the validity of the outcome, i.e., when a matrix of comparison has inconsistency, the decision maker must change his/her opinion about some comparison to improve the consistency of the outcome. In FAHP, this inconsistency cannot be showed and the inconsistency of judgment remains. "Uncertainty in AHP is successfully remedied by using intermediate values in the 1–9 scale combined with the verbal scale and that seems to work better to obtain accurate results than using fuzziness to change the numbers for convenience and rather arbitrarily" [43]. However, the objective of this article is not to assess the use of the method, but what methods were used.

Among the articles selected, 12 reported alternative methods, as can be seen in Table 1, Analytic Network Process (ANP) is an evolution of AHP [44] which uses a network structure to show the dependence between criteria and alternatives [35]; complex proportional assessment (COPRAS), which "works on a stepwise ranking and evaluation procedure of the alternatives in terms of their significance and utility degree." [31]; Elimination and Choice Expressing the Reality (ELECTRE) requires a defined criteria evaluation for the alternatives (decision matrix), preference information (weights), thresholds, and other parameters. "The method evolves the modeling of preferences with outranking relations, followed by an exploitation procedure" [28]; Grey Relational analysis (GRA) compares "the reference scheme and the optional schemes and the one which is closer can be selected as the best treatment alternative" [16]; Technique for order performance by similarity to ideal solution (TOPSIS) identifies solutions from a finite set of alternatives, in which "the optimal solution should have the shortest distance from the positive ideal solution and the farthest from the negative ideal solution" [12,15,26,29,39]; the compromise ranking method (called VIKOR) [45] "is a multi-attribute decision making technique which has a simple computation procedure that allows simultaneous consideration of the closeness to ideal and the anti-ideal alternatives" [18]; Max-min approaches which "maximize and minimize the operator performances against these weighted criteria" [21] and in the same article "non-parametrical statistical test to identify an effective operator set".

4.5. Check and balance of decision

In a few cases the authors reported the occurrence of a results validation process: [13] benchmarking was applied, for comparison with the application of the method for other organizations; some [11,31,39] used a sensitivity analysis; in one [39], the authors compared the result of the evaluation with actual data on distribution of segment area of industry; the results were similar; [38] used three methods to compare the results.

5. Conclusions

Vaidya and Kumar [2] affirmed that AHP is used to select from competing alternatives, allocation of scarce resources, and forecasting, but in the cases analysed, we notice that it is used mainly to weigh criteria and selecting and ranking alternatives. In the 33 selected articles, the origin of the problems is poorly reported, and the kind of knowledge sought was not determined, probably because the focus of the main journal used was technical.

The selection of criteria by the decision makers depended on the problem type: in the selection, the criteria arise from the organization's expertise; in the ranking of alternatives or of indicators, the literature was more used. The structure built utilizes the numbers seven plus or minus two for criteria and alternatives, in most of the cases, which permits a simplified, fast process. Only two cases related that the alternatives were previously

analyzed, which substiantially decreased their number, and only three cases showed this type of process about criteria, for example, the number of 109 criteria decreased to 20.

In the vast majority of the cases analyzed, decision makers would build a consensus among themselves and for that they used individual judgment agreggation. However, how the consensus was obtained and whether inconsistency in AHP application occurred were not commented on. To calculate the weights of criteria, AHP or Fuzzy AHP were used in all cases, except one; while the authors preferred the use of other techniques to asses the alternatives, such as TOPSIS, COPRA, ELECTRE. Another technique of AHP rarely used was rating, also called absolute judgment, which can render the AHP application faster and easier. The number of cases that used Fuzzy AHP is relevant, even though the father of AHP, Saaty, does not agree with that.

The comments about the result of the application of AHP relied only on the adequacy of the model and the techniques used for that. These findings can support the recommendation to future studies about the dificulties in applying AHP to choose the best criteria, to obtain consensus, and whether the results meet stakeholder expectation or whether the structure must be changed.

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