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USING MULTICRITERIA ANALYSIS AND FUZZY LOGIC FOR PROJECT PORTFOLIO MANAGEMENT

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ABSTRACT:

Goal: to propose a hybrid method, combining AHP and Fuzzy, for project portfolio management.

Originality/value: this paper meets the positive characteristics of both methods, adequately weighing the criteria and contemplating process subjectivity. Limitations that exist in both methods, such as the maximum number of alternatives and the difficulty of inserting new alternatives at the end of the process, are overcome.

Design/methodology/approach: the AHP is applied for determining the criteria weights and fuzzy is used to compare the alternatives for each criterion.

Results: the results show that the proposed hybrid method allows the ranking of many alternatives and provides higher reliability for decision makers. It must be noted that the system is fed by performance indicators, which minimize the subjectivity in decision-making—an important characteristic in the technology management. Moreover, the results provide the possibility of changing the number of projects at any time without influencing the outcome.

Practical implications: the proposed hybrid method can be used in different problems that have many alternatives or subjectivity.

Keywords: Multicriteria Analysis; Project Portfolio Management; Technological Management Fuzzy; AHP.

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1. INTRODUCTION

Financial resources, occasionally scarce in private and public sectors, ought to be carefully invested, and decision-makings by senior managers must be aligned with the strategic objectives of the enterprise and guided by non-subjective methods. Among the high-level decisions made in an organization, the ones that involve project portfolio management can be cited. The portfolio management should be closely linked with strategic actions by the enterprise, that is, the projects to be prioritized need to be the ones that are more connected with the strategic objectives of the organization. Additionally, it is important that this process be executed with technology management (Sabbag, 2013).

In this context, the objective of the Multicriteria Decision Analysis (MDA) is to help mathematically in the decision-making, as making the right choices, based on appropriate and aligned criteria, will be considered either as critical success factors or factors of organizational survival (Vargas, 2015).

According to Santis et al. (2017), surveys pointed out that AHP and fuzzy AHP methods, proposed by Saaty (1987) and Chang (1996), respectively, have been the most popular techniques to address the supplier selection problem so far.

The aim of this article is to propose an hybrid AHP+Fuzzy method for project portfolio management, in which the AHP will be applied to determining the criteria weights, and the Fuzzy Logic to processing the subcriteria. It will allow the ranking of alternatives (projects) as an option to the limitation of the Classic AHP method that only provides a maximum of nine alternatives (Saaty et Ozdemir, 2003).

It is important to emphasize that this study used the two theories, Fuzzy Logic and AHP method, differently from the Fuzzy AHP method—that is to say, they were used separately. Therefore, the term “AHP+Fuzzy method” was employed.

Fuzzy-AHP methodology is designed for decision-making problems and selecting the best of alternatives by integrating the concept of fuzzy set theory and hierarchical structure analysis. Certain characteristics of fuzzy methodology and AHP empower the decision maker to incorporate both their knowledge, which is mainly qualitative, and quantitative information into the decision model (Isaai et al. 2011).

Demirel et al. (2008) presented a timeline of work evolution using the Fuzzy AHP method where they report that the first works on Fuzzy AHP appeared in van Laarhoven et Pedrycz (1983) and in Buckley (1985). In them, the fuzzy ratios described by triangular membership functions were compared and the fuzzy priorities of comparison ratios membership functions trapezoidal were determined, respectively. Approximately a decade later, Stam et al. (1996) concluded that the feed-forward neural network formulation appears to be a powerful tool for analyzing discrete alternative multi-criteria decision problems with imprecise or fuzzy ratio-scale preference judgments. A new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pair-wise comparison scale off fuzzy AHP and the use of the extent analysis method for the synthetic extent values of the pair-wise comparisons was introduced by Chang (1996). A method to evaluate different production cycle alternatives adding the mathematics of fuzzy logic to the classic AHP was presented by Weck et al. (1997). These authors conclude that any production cycle evaluated in this manner yields a fuzzy set, and the outcome of the analysis can finally be defuzzified by forming the surface center of gravity of any fuzzy set. A fuzzy objective and subjective method were used by Kahraman et al. (1998) to obtain the weights from AHP and to make a fuzzy weighted evaluation. A new method for evaluating weapon systems by AHP based on linguistic variable weights was proposed by Cheng et al. (1999). Zhu et al. (1999) proved the basic theory of the triangular fuzzy number and improved the formulation of comparing the triangular fuzzy number’s size.

Mikhailov (2000) presented new Fuzzy Programming Method (FPM) for priorities derivation from pairwise comparison matrices, which is based on a geometrical representation of the prioritization process as an intersection of fuzzy hyperlines and determines the values of the priorities. It corresponds to the point with the highest measure of intersection.

Chen (2002) proposed an algorithm for external performance evaluation in the area of logistics from the retailers’ viewpoint under fuzzy environment.

Chan et Kumar (2007) identified and discussed some of the important and critical decision criteria including risk factors for the development of an efficient system for global supplier selection using fuzzy extended AHP-base approach.

Chamodrakas et al. (2010) proposed a fresh approach for the provision of decision support to solve the supplier selection problem in an electronic marketplace environment. Through their contribution, these authors modified Mikhailov’s Fuzzy Preference Programming method according to Liberatore’s rating scale AHP method.

Kilincci et Onal (2011) proposed a fuzzy extended AHP (FEAHP) approach using triangular

fuzzy numbers to represent decision makers’ comparison judgments and extent analysis method to decide the final priority of different decision criteria; their aim was to select the best supplier for a washing machine company.

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Dong et al (2012) emphasized the need for SSCPM (Service Supply Chain Performance Measurement) and developed a general framework to address the unique nature of service supply chain more adequately.

Kahraman et al. (2014) prioritized the possible investment alternatives in health research using a fuzzy multicriteria method, which has the ability to take the conflicting criteria into account. In this work, the analytic hierarchy process (AHP) method was utilized under fuzziness, which provides a mathematical way to represent vagueness in humanistic systems. Fuzzy AHP allowed the authors to evaluate possible alternatives using pairwise comparisons with fuzzy numbers. Among many fuzzy AHP methods in the literature, the Buckley's method, which is targeted with fewer objections than the others, was preferred for this work.

Oztaysi et al. (2017) proposed a prioritization method for possible business analytics projects using Type-2 fuzzy AHP. The proposed model is composed of six criteria, namely, strategic value, competitiveness, customer relations, improved decision-making, improved operations, and data quality. In this study, interval type-2 fuzzy sets are used to represent linguistic variables in order to reach more reliable results.

Santis et al. (2017) presented a decision model based on the Fuzzy Analytic Hierarchy Process method and its application in a real case of maintenance supplier selection in a large Brazilian railway operator.

Ding et al. (2017) developed two methods for hesitant fuzzy multiple-criteria group decision-making with group consensus; in these methods, all the experts used Hesitant Fuzzy Decision Matrices (HFDMs) to express their preferences. These two novel consensus models were applied in different group decision-making situations composed of consensus-checking processes, consensus-reaching processes, and selection processes.

Shaygan et Testik (2017) proposed a methodology based on Fuzzy Analytical Hierarchy Process (FAHP) for decision-making, integrated with cause-and-effect diagrams used in quality improvement studies.

Costa et al. (2018) described an original and simple variation on the usual ELECTRE methods to deal simultaneously with both multicriteria and multiple decision maker situations. It also incorporated the non-compensatory and non-dominance principles of ELECTRE while dealing with multiple decision makers evaluations. The results indicated that the ELECTRE ME was able to avoid the inconsistency of adopting contradictory mechanisms of aggregating preferences while modeling multicriteria and multiple evaluators.

Lin et Wang (2019) evaluated the reliability analysis of facility layout for an operating theatre. They proposed a new evaluation approach, which integrated the Fuzzy Analytic Hierarchy Process and human reliability tool, for optimization of facility layout design with safety and human factors in an operating theatre.

The key issue of this research was the proposition of a method of prioritization of C, T&I projects in portfolio management, aiming at the principles of efficiency in public management in view of the low financial resources from the State for research and development.

The methodology used in this work was: (i) the data was collected via questionnaires (applied to naval administrative specialists), by project performance indexes, and by direct observation; (ii) the application of the AHP+Fuzzy method comprises three different stages, which are detailed in Section "Hybrid method proposed"; and (iii) the AHP+Fuzzy method was compared with the Classic AHP method (Section "Experiments").

This work is organized as follows. The "Problem description" section presents the description of the problem, in which the peculiar aspects of the project management are approached as well as what was found in the literature. In the "Background" section, the AHP and Fuzzy Logic methods are described. The "Hybrid method proposed" section presents the AHP+Fuzzy method. The "Experiments" section discusses the carried out experiments and the analysis of their outcomes. Finally, the "Conclusions" section presents the paper's final considerations.

2. PROBLEM DESCRIPTION

The purpose of the project portfolio management is to optimize investment and strategic benefits for the organization by means of the execution of its programs and projects, seeking for balance between investments in projects underway and new strategic initiatives (Kerzner, 2006).

In times of resource contingency, the purpose of the project portfolio management is to prioritize projects that are of more strategic importance to the organization, considering the strategic objectives previously established and the performance of projects underway for the decision-making.

In order to know what decision-making method is more appropriate to manage a project portfolio, a bibliometric research in SCOPUS database was carried out. The research returned only three articles, all of them using the AHP method.

The first one (Turan *et al.*, 2008) mentions that the AHP method is applied to solve questions of decision-making aid

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using parameters of financial and non-financial performance in an energy-generation industry product in the United States. Financial performance, aging of labor force, energy initiatives, and emission control were defined as criteria. Although the authors consider that the outcomes were satisfactory, they admit that it would be relevant for future works to involve experts in the process.

In (Oliveira *et al*., 2013), the AHP is proposed for the selection and prioritization of research projects in the Brazilian Agricultural Research Corporation (EMBRAPA). The criteria and subcriteria selection were performed by means of interview with managers of the unit under study. To apply the method, six projects were chosen; they were ranked from six criteria and 15 subcriteria. The established criteria were as follows: strategic alignment, technical aspects, creativity, budget, possibility of product/service development, and possibility of technology transference. Among the results, the authors called attention to the strategic alignment to achieve portfolio management success.

Lastly, in (Yu *et al*., 2014) the AHP is presented as a solution for prioritization of two project clusters, focusing on the production management instead of the portfolio management. The project clusters are defined as volume-oriented projects and profit-oriented projects. This case study selected three criteria, each of which unfolded into three subcriteria, thus totaling nine subcriteria. The authors defined the criteria as market requirements and competition; management and technological ability; and financial planning and analysis. The results presented highlighted the strategic importance of the profit-oriented projects; however, the results presented numerous difference among them.

The results obtained from the cited articles were satisfactory; nevertheless, for the presented studies, the number of alternatives was fewer than nine projects, which is a limiting factor for many organizations that have a higher number of projects underway in their portfolio.

Dividing the process into three phases would be a solution for this problem. The first phase would use the AHP to determine the criteria weight; the second one, the Fuzzy Logic to score the projects; and the third phase to apply both methods in a hybrid way so as to obtain the result for projects.

As there were no correlated works that establish a connection between AHP and Fuzzy and project portfolio management in the SCOPUS database, Google Scholar was consulted. The articles found are described below.

In (Agrawal *et al*., 2016), the AHP is applied to score the criteria and, together with the Fuzzy-TOPSIS, choose the more adequate reverse logistic method in a telecommunication technology company. The author proposes the joining of the methods aiming to reduce the criticism over the AHP method in relation to the fundamental scale used for the pairwise comparison.

In (Nilashi *et al*., 2015) it is proposed that the AHP method be applied together with the Fuzzy Logic to measure how sustainable a specific construction is. However, they used the methods separately, The research started by employing the AHP to select the most important factors for the evaluation of building performance, after which the Fuzzy Logic was applied for obtaining a single value, analyzing in a quantitative way how green or sustainable the building is.

Lastly, in (Schauenburg, 2014) the AHP method and the Fuzzy Logic are presented in a coupled way to solve the need of managing a project portfolio by means of using the AHP method for the criteria score, and the Fuzzy Logic for the project score in relation to the subcriteria; an interview with experts was the input data.

This article suggests the AHP method application and the Fuzzy Logic sequentially. The work of Schauenburg (2014) can be cited as a correlated text regarding the objective and the methods, highlighting that this article uses project performance indexes as input data of the fuzzy system, while the correlated work applies the results from the interview.

3. BACKGROUND

In this section the multicriteria decision analysis method AHP and the Fuzzy Logic method are described, which are combined to compose the proposed hybrid method.

Analytic Hierarchy Process (AHP) Method

AHP has as its main characteristic the ability to convert empirical data into mathematical models. The mathematical values will be processed and compared. For each of the factors, weights will be attributed to evaluate the elements into the defined hierarchy.

The first step consists of the definition of the decision hierarchy, in which the main objective is at its first level; the associated criteria, at the second level; and lastly, the available alternatives (Figure 1).

To measure the relative importance as well as the preference level among the criteria and, subsequently, among the alternatives, the comparisons of all criteria are carried out, pairwise, at each level of the decision tree. After that stage, the alternatives are compared pairwise concerning each criterion. Concerning the pairwise comparison among the

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elements, it is recommended that it be made through the use of verbal responses employing the Fundamental Scale proposed by Saaty (1980), attributing values that range from 1 to 9, according to Chart 1.

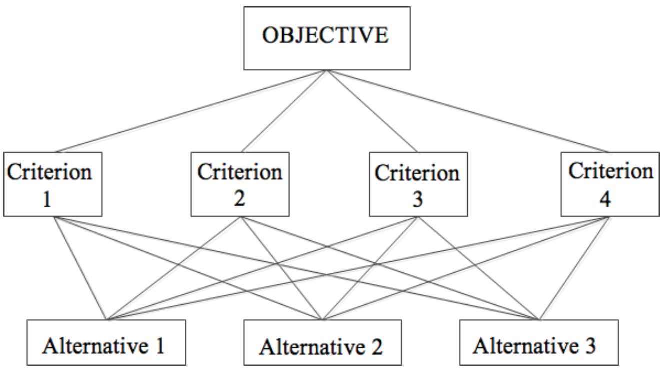

Figure 1. Graphic Representation of the Decision Hierarchy (Saaty,1980).

Chart 1. Fundamental Scale of Saaty

Scale	Numeric Evaluation	Reciprocal
Extremely preferred	9	1/9
Very strong and extreme	8	1/8
Very strongly preferred	7	1/7
Strong and very strong	6	1/6
Strongly preferred	5	1/5
Moderate to strong	4	1/4
Moderately preferred	3	1/3
Equal to moderate	2	1/2
Equally preferred	1	1

Source: (Saaty, 1980).

As showed in Chart 2, a comparison matrix is built by using the Saaty scale. Lastly, it is essential to verify the data consistency by means of the Consistency Index (CI) calculation.

Chart 2. Comparative matrix
(suppose criterion 1 dominates criterion 2)

	Criterion 1	Criterion 2
Criterion 1	1	Numeric Evaluation
Criterion 2	1/ Numeric Evaluation	1

Source: adapted from (Saaty, 1980).

Fuzzy Method

The Fuzzy Logic has as an attribute the possibility of associating linguistic and numeric data by means of a database and a rule set. A fuzzy inference system accepts crisp numbers as input, which carries out a fuzzy inference processing by means of a linguistic rule base, and returns to the external environment as processed output, also crisp. The diagram showed in Figure 2 illustrates in a generic way an example of classic processing, composed of fuzzification, rule base, and defuzzification elements.

The linguistic rules can be provided by experts or artificial intelligence algorithms (Schauenburg, 2014). The inferences characterize the combination relation between the system inputs (premises) and the outputs (conclusions). The inference component will be responsible for the rule identification, which will be activated taking into consideration the input data, or premises, that will be affected in some degree of pertinence by the mapping of the initial interface. In this phase, the fuzzy outputs will be obtained by means of the operation performance on the sets and the relation establishment, joining the results of the inference rules.

Finally, the defuzzification stage, such as the output translation obtained using the pertinence of the output variable terms in crisp numbers, returns an accurate outcome for the process (Nicoletti et Camargo, 2013).

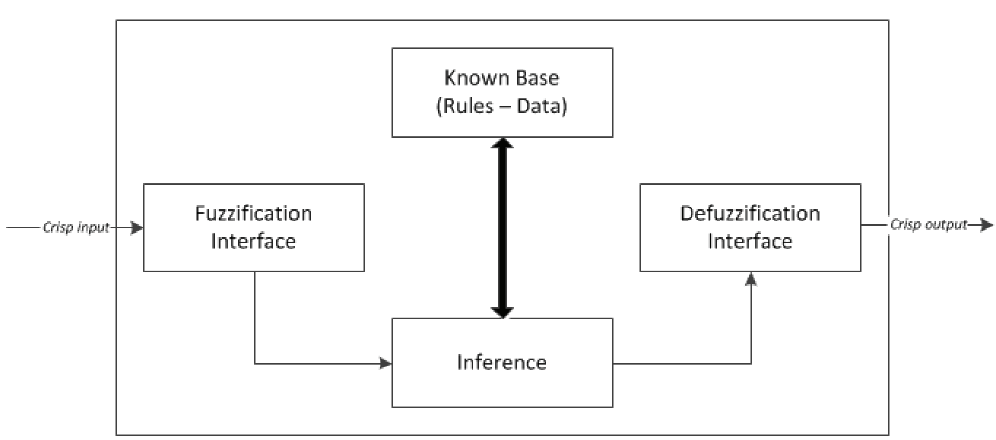

Figure 2. Generic diagram of a fuzzy inference system - adapted from Schauenburg (2014).

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4. PROPOSED HYBRID METHOD

The experiments consist of the AHP method application to define the criteria and subcriteria weights that are in the decision hierarchic structure of the fuzzy processing to attribute a grade to each project in relation to the subcriteria and of the proposition of the result composition of both methods to the project ranking. The method is also applied to the execution of the classic method to compare the methods.

Application of the AHP Method

As proposed by Saaty (1980), the decision hierarchic structure must be firstly created as illustrated in Figure 3. Based on official documentation, to fulfill strategic organization goals concerning science, technology, and innovation, the selected criteria aimed to measure the project's ability of performance and strategic alignment. The subcriteria were chosen to meet the enterprise's strategic goals, which are the following: financial resources, capacity for managing, technical capacity, strategic technology, customer relationship, and potential to create innovation.

The criteria and subcriteria will not be detailed in this work in view of the specificity to the organization in question.

The second phase, as proposed by Saaty (2008), consists of the construction of the pairwise comparison matrices to carry out the paired comparison. They are to occur among the elements of a hierarchy level concerning the preference among the criteria and how preferred the chosen criterion is—in relation to the one that was not selected in accordance with the Fundamental Scale of Saaty. Thus, the criteria were initially compared (Table 1), and the comparison among the respective subcriteria was performed (Table 2 – Criteria "Potential for Achievement" – and Table 3 – Criteria "Strategic Alignment"). All parity comparisons were consistent since CRs were less than .

Table 1. Comparative matrix between criteria

	Potential for Achievement	Strategic Alignment
Potential for Achievement	1	3
Strategic Alignment	1/3	1

Table 2. Comparative matrix between subcriteria "Potential for Achievement." CR = 4.62%

	Fin Resources	Cap. for Managment	Tech. Capacity
Fin Resources	1	1/3	2
Cap. for Managment	3	1	3
Tech. Capacity	½	1/3	1

Table 3. Comparative matrix between subcriteria "Strategic Alignment." CR = 3.18%

	Strat. Tecnology	Rel. to Society	Pot. to Creat. Innovation
Strat. Tecnology	1	9	4
Rel. to Society	1/9	1	1/4
Pot. to Creat. Innovation	1/4	4	1

The comparisons were made through the participation of naval administrative specialists, who also validated the final result obtained. Figure 4 shows each subcriterion in order of priority.

Fuzzy Processing

For each subcriterion, there is a set of at least two performance indexes, which will be part of the processing as input data. The modeling was specifically performed for each index set taking into consideration the experience of the experts. In view of the modeling specificity and the number of processings executed, the models will not be presented in this study.

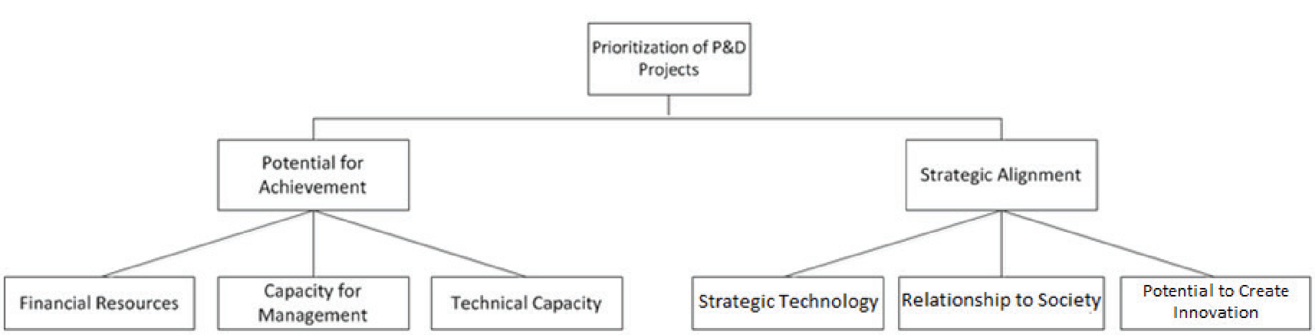

Figure 3. Decision Hierarchy Structure of the Proposed Objective.

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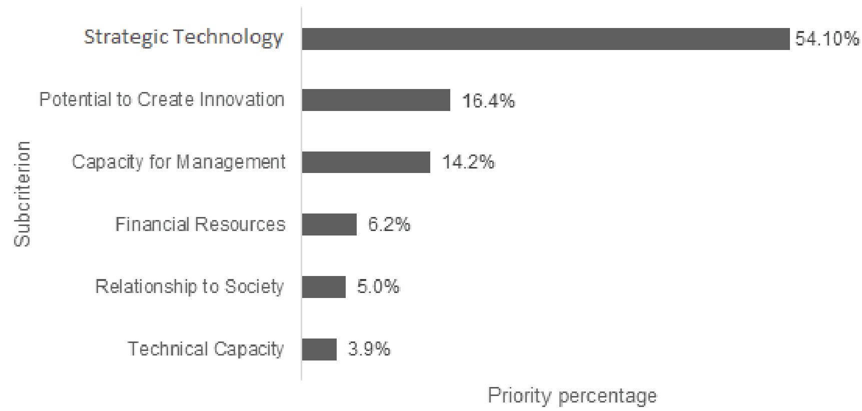

Figure 4. Subcriteria in increasing order of priority.

Figure 5 generically exemplifies the fuzzy processing used to attribute a grade to each project. All analyzed projects had performance indexes in their database, yearly evaluated by the enterprise, and directly related to the strategic goals. For instance, considering the *"x"* subcriterion, the project Proj.1 presents the performance indexes 1 and 2 to the fuzzy inference system, which, by means of rules based on the knowledge of the experts, provide a processed output to the external environment that, in this case, will be the attribution of a grade to the Proj.1 in relation to the *"x"* subcriterion.

In this article, the processing will occur six times the number of the existing projects, and for each subcriterion, there will be a set of specific rules to model the relation that should exist between the performance indexes so that the project presents the best performance referring to the subcriterion concerned.

The inference system applied was Mamdani's, which has as base the max-min composition rule (Mamdani, 1974). We did not test other models.

The defuzzification model was the Middle of Maximum—MOM in all models, as between the ones available in the MatLab (centroid), First of Maximum—FOM and Middle of Maximum, the Middle of Maximum was the one that presented the best results when the extreme values of 0 and 1 were evaluated.

Proposed Hybrid Method – AHP+FUZZY

After performing all the fuzzy process, each project will have a grade for each subcriterion. The proposed hybrid method consists of multiplying each grade by the corresponding subcriterion weight; this set of values is normalized so that the *N* projects have an attributed value to make the ranking possible in order to carry out the prioritization of the projects.

It is worth highlighting that the hybrid method is different from the AHP-Fuzzy method. The latter is similar to the Classic AHP method; nonetheless, the inputs are triangular fuzzy numbers, while in the proposed solution the methods are applied for a joint resolution.

5. EXPERIMENTS

In this section the results will be discussed. Prior to that, however, the portfolio of the projects considered is presented for analysis.

Projects Description (Alternatives)

Considering the need for information security of some projects, because of their sensitive information, the names of the projects will not be presented. A brief description will be made to promote a more comprehensive understanding of the results:

- **PS Project** – it is a project that focuses on improving the oldest product developed by the enterprise. It aims to optimize the data analysis of the marine environment (operational) to meet the operational needs of the organization. The goal of the project is of strategic interest;

- **PC Project** – it is a long project due to its complexity and demands high investment, especially in infrastructure. It has budgetary resources and research development enterprise resources. Coupled with it, there is a set of smaller projects whose objectives are to meet its goals. Currently, half of the planned time for development has elapsed. It also has a patent deposit. The goal of the project is of strategic interest;

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- **PP Project** – it is a medium-duration project whose goal is to create specific database to the operational needs of the organization. It is also of strategic interest;

- **PM Project** – it is a new project of scarce financial resources, as the existing laboratorial structure suffices to its necessities. This project does not serve any of the strategic projects directly; and

- **PB Project** – it is a long project of biotechnological product development. It has high academic integration in view of the number of scholarships for master's and doctoral students who are engaged in many project activities. It benefits from a considerable number of fundraising from agencies as well. The project has a set of smaller projects that aim to fulfill its goals and a granted patent deposit. However, this project does not directly serve any of the strategic projects.

Result Analysis

The results obtained by means of the Classic AHP and the AHP+Fuzzy methods will be presented so a comparison is enabled. The overall results of the project ranking are graphically represented in Figure 6.

The results obtained by the proposed hybrid method were satisfactory in consideration of the correlation index of 0.964 with the result achieved by the classical method. The overall results of the project ranking are graphically represented in Figure 4.

A positive aspect observed was the ability of the proposed method to evaluate the project under the strategic aspects, financial situation, and the existence of infrastructure, while the classic AHP only evaluated the strategic performance. That can be observed among the methods, more specifically between projects "PP" and "PM."

Project "PM," although not a strategic one, presented superior performance with lower cost, which can be identified by the proposed hybrid method, but not by the classical method AHP.

Another important project to be analyzed is the "PB" project, which presents technically identical results. However, it has a high cost despite its low strategic alignment. On the other hand, it shows excellent results regarding the fundraising, that is, it does not depend solely on the organization to be conducted. Moreover, it presents a high level of relationship with society and potential to create innovation. Therefore, despite not presenting a strategic interest, this project displays excellent results and uses few governmental resources, a performance that is only presented by the hybrid method.

With regard to the analyses presented, it can be concluded that the results of the hybrid method were satisfactory compared to the results of the classic method.

It is relevant to highlight that there were only five projects underway to be ranked in this work; nonetheless, if there were more projects, the application of the classic method would be affected due to the limitations of the method concerning the number of possible alternatives. Therefore, the use of the proposed hybrid method would meet the needs of the organization regardless the number of projects (alternatives).

6. CONCLUSIONS

Based on the literature review and the bibliometric analysis, the AHP method is verifiably the most used multicriteria method. However, when searching for publications relating to project portfolio management using the AHP method, the results are still restricted and recent, with dates from the last 5 years.

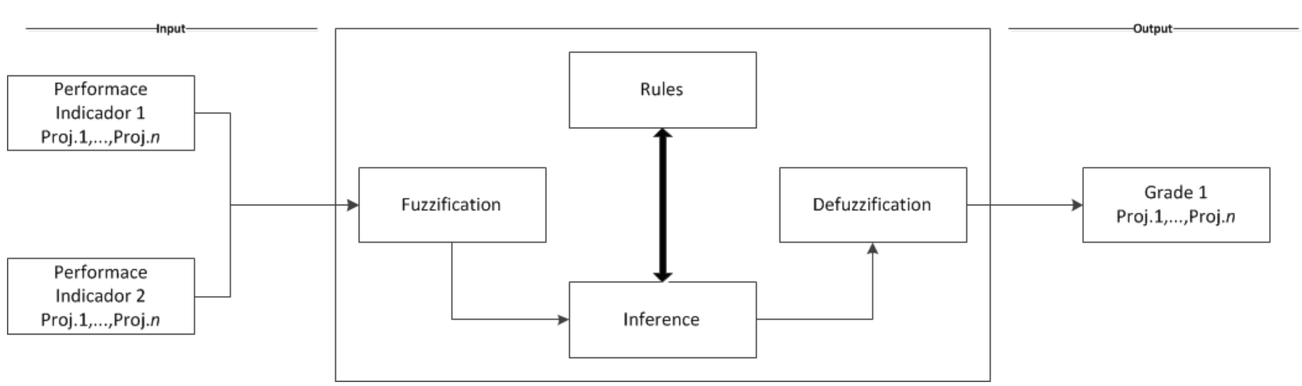

Figure 5. Generic scheme of fuzzy processing.

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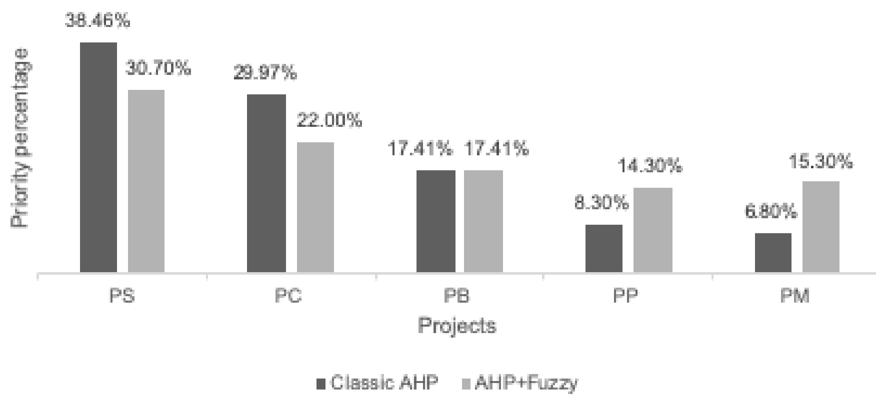

Figure 6. Comparison among the ranking results between the methods.

The application of the AHP method to obtain criteria weights was performed through the participation of naval administrative specialists and researchers, who also validated the final result obtained. The proposed hybrid method, AHP+Fuzzy, was compared with the Classic AHP method and the results obtained were considered satisfactory, taking into account that the final result obtained a correlation index of 0.964 between the methods. Thus, the use of the proposed hybrid method for the problem addressed was satisfactory. This use has an advantage over the Classic AHP method, since it is able to work with a high number of alternatives.

Furthermore, the proposed hybrid method has the characteristic of providing greater certainty for the decision makers, since the system is fed by performance indexes, thus minimizing subjective impressions on decision-making. It also enables the possibility of changing the project number (alternatives) at any time without undermining the results. It is noteworthy that all the processing can lead to computational automation; for that, the input data of the fuzzy system is needed according to the specific periodicity of each organization. It is recommended that for each update of the Strategic Organizational Planning the AHP processing and the fuzzy modeling be carried out again, taking into consideration the possible strategic changes of the organization. This process will generate a more complete technology management of portfolio.

However, keeping a monitoring and project control methodology is needed in order for the data based only on the manager's information not to overestimate or underestimate the results and the development of the projects, thus damaging the funds passed to the decision makers.

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