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PROJECT PORTFOLIO MANAGEMENT WITH THE SUPPORT OF THE AHP METHOD

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ABSTRACT

Project Portfolio Management (PPM), fundamental for companies to adapt to the scenarios and achieve their strategic objectives, requires the use of a tool to aid decision making in the selection of projects. This study aimed to present a theoretical example of PPM, using the Analytic Hierarchy Process (AHP), as a strategy to justify the decision. It was implemented with the support of a well-known and widely available spreadsheet, avoiding the use of proprietary software. It is concluded that the proposed model is feasible and, based on the resources available in it - sensitivity and consistency analysis, the different aspects of the PMM can be more easily verified, allowing the decision-maker to not just determine and justify its decision-making, but to learn and improve their decision-making process.

Keywords: Project Portfolio Management; Analytic Hierarchy Process; Multicriteria Decision.

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1. INTRODUCTION

Project Portfolio Management (PPM) has become, over the years, a fundamental element in reaching the strategic objectives of various companies, by supporting the decisions necessary for the selection of projects in their portfolios. Through PPM it is possible to organize and prioritize several projects in a single portfolio, which facilitates their management from different models. However, the implementation of PPM is a very complex task, since several factors, such as costs, deadlines and resources should be considered. Thus, the use of one of the Multi-Criteria Decision Analysis (MCDA), which emerged as a field of Operational Research, to assist companies in their decision-making processes, is of great importance when it is applied in PPM. In this case, the decision-making model chosen to be applied to a theoretical case of PPM is the Analytic Hierarchy Process (AHP), understood in this study as much more than a simple step-by-step, a method or a process - as mentioned by its developer, Thomas L. Saaty - but as a set of techniques that allow modeling, solving and simulating a decision-making problem.

In the market, there are some programs, such as AUTOMAN, Criterion, Expert Choice, HIPRE3+, NCIC, IPÊ and Superdecisions, which implement the AHP and provide the simplification of the evaluation process, execution of matrix calculations and consistency indexes. Despite the practicality of using these specialized programs, the application discussed in this article uses the Microsoft® Office Excel spreadsheet, easily available and easy to implement, in order to provide a more didactic and accessible approach to anyone who wants to use AHP as a model.

Thus, the use of the AHP model through non-proprietary software is presented as an example for the process of solving the PPM problem in a company, in which the benefits of consistency and sensitivity analysis of the mathematical model capable of taking into account the subjectivity of the decision maker, thus helping in decision making, as well as the performance of a better analysis, comparison and prioritization of the portfolio of the projects in question.

This manuscript is subdivided into five sections, including this Introduction; the theoretical reference, which brings the arguments that support the research; the Methodology adopted for the development of the research; Analysis of results, showing the application of the model studied in a theoretical problem, but based on a real case, in which the obtained results are displayed and examined; and, finally, the Final Considerations, which bring the limitations of the research, suggestions for future research and a succinct conclusion.

2. THEORETICAL REFERENCE

2.1. Project Portfolio Management – PPM

A project is understood as a unique enterprise that is characterized by a sequence of events with beginning, middle and end, which is intended to achieve a clear and defined goal, being led by people within predefined parameters of time, costs, resources involved and quality (Vasconcelos et al., 2013). Project Management, in turn, is defined as the planning, scheduling and control of various integrated tasks so that the objectives are achieved successfully, benefiting all stakeholders (Kerzner, 2007). According to Vargas (2009), to understand what project management is, it is important to know clearly what a project is, as shown in Figure 1.

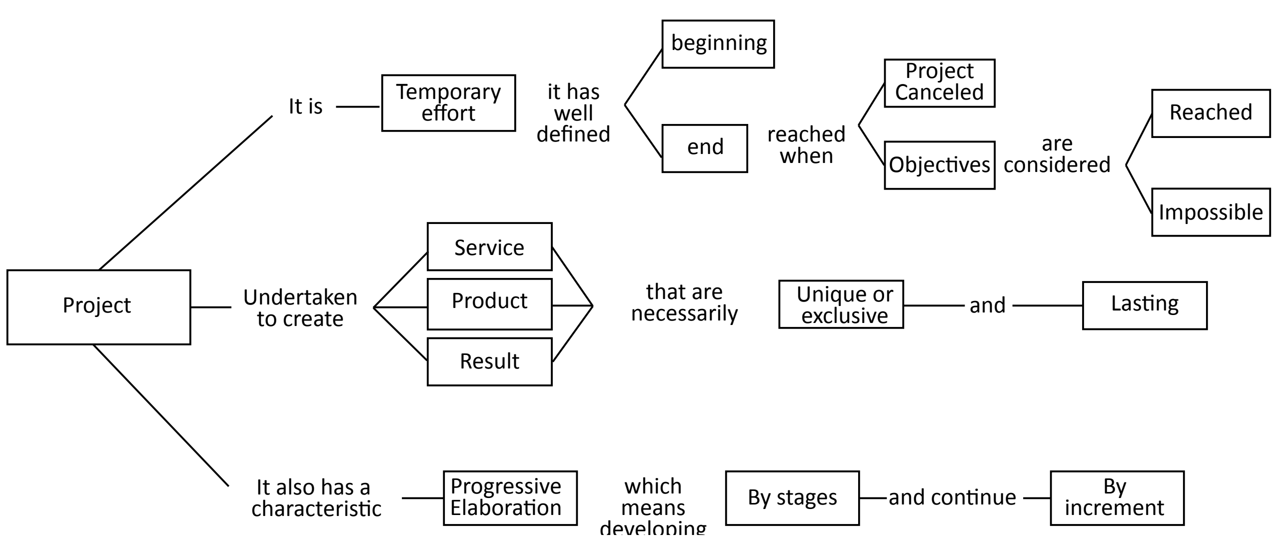

Figure 1. Project definition
Source: Adapted from Goldman (2015)

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The project portfolio is a collection of projects, conducted under the management of a unit of a particular organization; each project can be related or independent of the others, sharing the same strategic objectives and competing for the use of resources (Cooper et al., 1997 *apud* Correia, 2005). Its components are quantifiable, that is, they can be measured, classified and prioritized (PMI, 2006). Because PPM occurs at the strategic level of organizations, as illustrated in Figure 2, its main objectives are to identify, select, fund, monitor, and perform an appropriate mix of projects and initiatives in order to achieve organizational goals and objectives (Padovani, 2013).

Figure 2. PPM Organizational Context
Source: PMI (2006)

In this sense, PPM ends up being an ordering that is based on the cost/benefit ratio of each project. This is not only related to financial criteria, but also to the gains and efforts required to carry out each project. Due to the complex, variable and chaotic scenario in which organizations are inserted, the biggest challenge lies in determining what is cost and what is benefit to each organization (Vargas, 2010).

2.2. Multicriteria Decision Support Approach

The multicriteria approach has as its characteristics several actors involved, defining the relevant aspects characteristic of a complex decision process, with each actor having his/her own judgment of values and recognizing the limits of objectivity, taking into account their subjectivities (Gomes et al., 2009). A multicriteria decision problem consists of a situation in which there are at least two alternatives of action to choose from and this choice is conducted to meet multiple criteria, often conflicting with each other. In order to build the decision model that will represent the decision problem to be addressed, multicriteria decision support models are used (Vasconcelos et al., 2013), as they are fundamental in the analysis and structuring of multicriteria decision problems (Almeida, 2011).

2.2.1. AHP Model

According to Costa et al. (2013), in a process that considers different evaluation criteria, an additive and compensatory model, as developed by Prof. Thomas L. Saaty in 1977, is a Multicriteria Decision Support model that aims at the selection, choice or prioritization of alternatives. The AHP is a multicriteria method of analysis based on an additive weighting process, in which the performances of the alternatives, in relation to each criterion, are represented by their relative importance (expressed in percentage). This model has the advantage of allowing the comparison of quantitative and qualitative criteria, and also considering the subjectivity involved in decisions (Moraes et Santaliestra, 2007). The AHP model aims at converting the judgments of decision makers into percentage values (relative priorities), so that, with the use of additive weighting, global performances are calculated for each alternative, allowing immeasurable elements to be compared, aiding decision making for achieving the main goal (Oliveira Neto, 2009).

Thus, the AHP produces a global percentage value for each of the potential actions (alternatives), prioritizing or classifying them. The additive weighting - in which the performances of the alternatives in relation to each criterion are represented by their relative importance (expressed in percentage) - means making, for each alternative, the sum of the performances multiplied by the percentage weights of the respective criteria (Goldman, 2015). It is one of the most well-known and widespread multicriteria decision support tools, with the largest number of applications reported in the literature (Vaidya et Kumar, 2006; Tortorella et Fogliatto, 2008).

One of the difficulties in using the AHP model in a decision making process is the number of paired comparisons required, which grows very fast, increasing, therefore, the matrix to be elaborated. However, there are different points raised by the critics of the AHP, such as the alteration of dominant alternatives according to the inclusion or exclusion of irrelevant alternatives, known as the reversion effect of the priority order (Shimizu, 2006), and that has been debated in the relevant literature, but whose deepening would have escaped the scope of this article (Goldman, 2015). According to Vargas (2010), calculations involving the AHP model may appear easy, but in more complex cases, they can become long and tiring; thus, it is convenient to use some software specifically designed for the model. Figure 3 shows the application of AHP in several areas.

Electronic Journal of Management & System
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Priority settings
Cost and benefit assessment
Resource allocation
Benchmarking
Market valuation or research
Determination of requirements
Strategic decisions (Forward & Backward Planning)
Activity planning and sequencing
Forecasting
Negotiation and resolution of conflicts
Political or social decisions or forecasts
Decision analysis at risk

Figure 3. Examples of AHP model applications
Source: Pacheco (2015)

2.3. Model – definitions and discussion

2.3.1. Structure of the decision-making process

The use of AHP begins by decomposing the problem into a hierarchy that is more easily analyzed and independently comparable. From the moment this logical hierarchy is constructed, decision-makers systematically evaluate alternatives through peer-to-peer comparisons within each of the criteria (Vargas, 2010). According to Salomon (2004), the decision under multiple criteria can be hierarchically decomposed into levels, as shown in Figure 4.

I. The first level of the hierarchy consists of the goal, which is the purpose of the problem, also called the goal of the decision;

II. In the second level the criteria are arranged, and sub-levels with subcriteria may also exist, if necessary;

III. The last level presents the alternatives for solving the proposed problem.

2.3.2. Saaty's fundamental scale and paired comparisons

After constructing the hierarchy, decision-makers systematically evaluate the alternatives through comparisons, two by two (paired), within each of the criteria, and the criteria in relation to the objective (Silva et Belderrain, 2005).

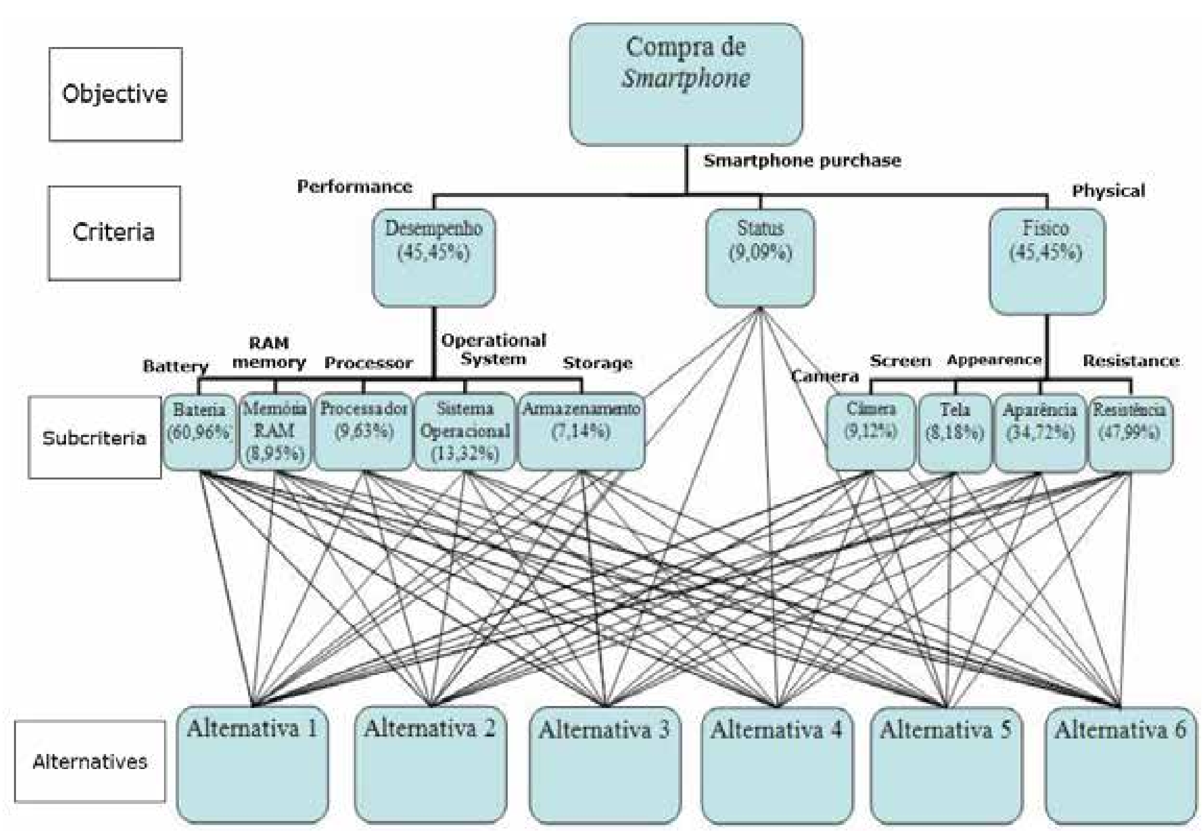

Figure 4. Example of Hierarchical Structure
Source: Veríssimo et Goldman (2017, p. 6)

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In this way, a square, reciprocal, positive matrix, known as the Pairwise Comparison Matrix, is generated expressing the degree of dominance of an alternative in relation to the others. The comparison of alternatives is used performing its own scale, which varies from 1 to 9, and is called Saaty Fundamental Scale, as shown in Table 1.

The number of judgments required to construct a generic judgment matrix A is *n*(*n*-1)/2, where *n* is the number of elements belonging to this matrix - Equation 1.

Comparison Matrix **A** (Equation 1)

$$A_{n\ x\ n} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix}$$

In which:

$a_{ij} = \alpha > 0$ (positive);
$a_{ji} = 1/\alpha$ (reciprocal);
$a_{ii} = 1$, if i=j.

Where:
a – comparison between the criteria
α – intensity value of importance
(Abreu et al., 2000, Marins et al., 2009)

2.3.3. Decision Matrix

In the Decision Matrix, Table 2, a matrix n (number of alternatives) x m (number of criteria) - which is the last step of the modeling, vectors of relative priorities and weights are consolidated, and additive weighting is performed.

2.3.4. Consistency analysis

The Consistency Analysis check aims to capture whether the decision makers were consistent in their opinions for decision making (Teknomo, 2006). The procedures for calculating the Consistency Ratio (CR) and the Consistency Index (CI) are described as follows, from a model proposed by Saaty, after examining 500 matrices with total consistency (Marins et al., 2009):

The so-called Weighted Sum Vector is determined by making the matrix product of the original Pairwise Comparison Matrix by the vector, whose terms are the weights obtained for the respective criteria - Equation 2;

Weighted Sum Vector (Equation 2)

$$\begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} \times \begin{bmatrix} W_1 \\ W_2 \\ \cdots \\ W_n \end{bmatrix} = \begin{bmatrix} vS_1 \\ vS_2 \\ \cdots \\ vS_n \end{bmatrix}$$

Table 1. Basic Scale of Saaty

1	Equal importance	Both activities also contribute to the goal
3	Small importance of one over the other	Experience and judgment favor an activity slightly over the other
5	Large or essential importance	Experience and judgment strongly favor one activity over another
7	Very large or demonstrated importance	One activity is very strongly favored over the other; its domination of importance is demonstrated in practice
9	Absolute Importance	Evidence favors one activity over another with the highest degree of certainty
2, 4, 6, 8	Intermediate values	When you look for a commitment condition between two settings

Source: Adapted from Saaty (1990)

Table 2. Decision Matrix

Decision Matrix	**Criteria →**	**C1**	**C2**	**...**	**Cn**
	Weights →	**W1**	**W2**	**...**	**Wn**
Alternatives	A1	A11	A12	...	A1n
	A2	A21	A22	...	A2n
	...	...	...	...	...
	Am	Am1	Am2	...	Amn

Source: Pacheco (2015)

Electronic Journal of Management & System
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Depois, Then, the results obtained should be divided term by term by the respective term of Vector W; therefore, the Consistency Vector (VC) is obtained - Equation 3;

Consistency vector (Equation 3)

$$\begin{bmatrix} Vs_1/w_1 \\ Vs_2/w_2 \\ \vdots \\ Vs_n/w_n \end{bmatrix} = \begin{bmatrix} vC_1 \\ vC_2 \\ \vdots \\ vC_n \end{bmatrix}$$

By averaging the results of the *n* lines, λmax is obtained - Equation 4;

$$\lambda\, máx = (Vc_1 + Vc_2 + \cdots + Vc_n)/n$$

Consistency Index (CI) is calculated, where n is the number of items compared - Equation 5;

$$CI = (\lambda\, máx - n)/(n-1)$$

The Consistency Rate or Ratio (CR) is obtained - Equation 6.

$$CR = CI/RI$$

The value of the Random Index (RI) depends on the order of the Pairwise Comparison Matrix, as shown in Table 3.

Table 3. Values established for the Random Index (RI)

RI as a function of n						
N	3	4	5	6	7	8
RI	0,58	0,90	1,12	1,24	1,32	1,41

Source: Adapted from Marins et al. (2009)

For the AHP model it is expected that the CR of any comparison matrix is less than or equal to 0.10 (Marins et al., 2009). Thus, if CR ≤ 0.10, the matrix has an acceptable level of inconsistency (Taha, 2008).

2.3.5. Sensitivity Analysis

Sensitivity Analysis is a tool available for the validation of the adopted model and the results. However, each problem must be analyzed according to its peculiarities, with the possible realization of sensitivity analyzes since they strongly imply a more accurate understanding of the problem (Vieira, 2006), with emphasis on four types:

- Changes in the relative weights of the criteria - through the matched comparison, a small change from the original value evaluated is made for all comparisons; or "all possible spectrum" is exhausted, making all comparisons for all criteria using all the variation of the Fundamental Scale (from 1/9 to 9);

- Alterations of the judgments of the alternatives - a review of the evaluation of the original judgments is made and some values of the comparisons are altered;

- Changes in the number of criteria - when insertion or withdrawal of a criterion occurs;

- Changes in the quantity of alternatives - when insertion or withdrawal of an alternative takes place; the performance of some alternatives can be influenced in the midst of new alternatives, altering the result expressively.

3. SCIENTIFIC METHODOLOGY

3.1. Application of the AHP model

It shows the application of the model studied in a theoretical problem, based on a real case, in which the obtained results are displayed and examined.

3.1.1. Problem description

A large energy company, hereinafter referred to by the fictitious name "Company" - which operates in the exploration, production, refining, commercialization, transportation, petrochemical, distribution of by-products, natural gas, electricity, gas-chemical, and biofuel sectors - is taking measures to overcome the difficulties of the current economic moment. One of the measures is the reorganization of the company's project portfolio. The PPM carried out with excellence will be of fundamental relevance to the "Company". To this end, a new Business and Management Plan (PNG) is being implemented, as shown in Figure 5.

This paper presents a simplified theoretical example, extracted from a real case, of the use of the AHP model in the Company's PPM. For this, the Saaty Fundamental Scale, Table 1, was used through a face-to-face interview, in which a questionnaire was filled out with the necessary compari-

Electronic Journal of Management & System
Volume 12, Number 3, 2018, pp.295-310
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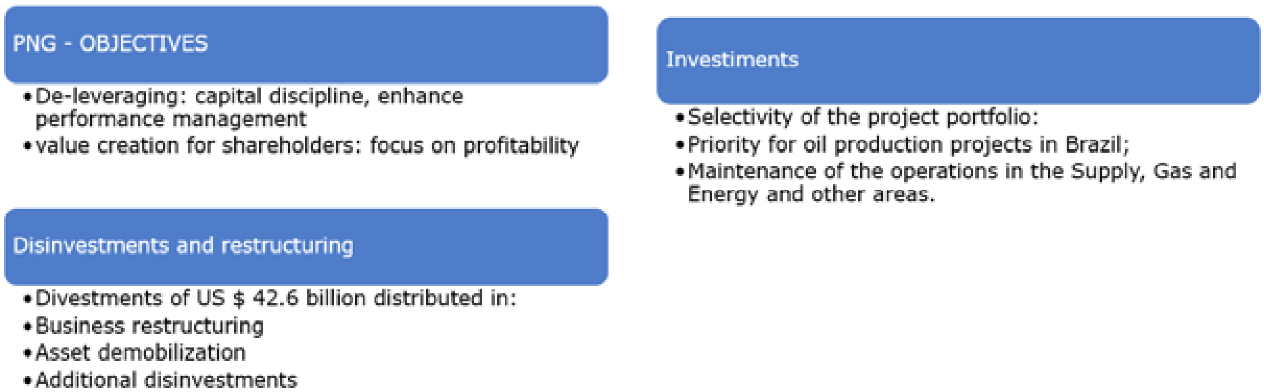

Figure 5. Business Plan and Management (BPM)

Source: Adapted from the Company (2016)

sons, in this example, with a single company manager. The judgments regarding the comparison of the criteria and the alternatives among themselves in relation to the criteria were collected. With the collection of these judgments, the matrices of Pairwise Comparisons were set up, giving rise to the relative priorities of the alternatives and the weights of the criteria, which were consolidated in the Decision Matrix, in accordance with Saaty (1990, 2008), Shimizu (2006) and Costa (2002). The criteria of prioritization of projects used in this work were defined according to the example of Vargas (2009):

- Financial – set of criteria to capture the financial benefits of the project. They are directly associated with costs, productivity and profits;
- Strategic - set of criteria directly related to the strategic objectives of the organization;
- Risks (threats) - it determines the level of risk that the organization runs when carrying out the project;
- Urgency - determines the level of urgency of the project;
- Technical Knowledge - evaluates the technical knowledge needed to carry out the project. However, this criterion was disregarded because it was evaluated with the same performance for all projects.

As an example, four projects were chosen for presentation in this article, as illustrated in Table 4.

3.1.2. Structuring the problem

Layout of hierarchical levels of basic structure - problem described above, as illustrated in Figure 6.

Table 4. Projects

Code	Project	Objective	Total investment
A	Pipeline plan	Mitigate the hazards of pipelines by withdrawing the oil pipelines from densely populated regions and allocating them in the pipeline corridors	R$ 200.000.000,00
B	Adequacy of the Industrial Dump Treatment Station	To adapt the effluent treatment capacity and fit its parameters to the current legislation	R$ 130.000.000,00
C	Adequacy to eliminate logistics bottlenecks	Eliminate logistical bottlenecks in response to market needs	R$ 170.000.000,00
D	Adequacy of the liquefied petroleum gas sphere	Improve the capacity to receive Liquefied Petroleum Gas with consequent reduction of freight, as well as reduce operational risks	R$ 30.000.000,00

Source: Data adapted from the “Company”, 2016

Electronic Journal of Management & System
Volume 12, Number 3, 2018, pp.295-310
DOI: 10.20985/1980-5160.2018.v13n3.1309

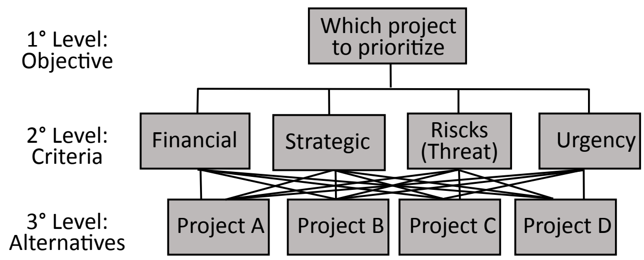

Figure 6. Decision tree

Source: Data adapted from the "Company", 2016

4. ANALYSIS OF RESULTS AND DISCUSSION

4.1. Results of the application of the AHP model

After the presentation of the projects (Table 4) and the criteria (Figure 6) required and after the application of the Saaty Fundamental Scale (Table 1) to the paired comparisons, the result shown in Table 5 is obtained.

Table 6 shows the weights assigned to each criterion, obtained through the process of calculating the mean of the normalized values.

It can be seen that the Financial and Strategic criteria are more important than the criteria Risk (Threats) and Urgency. Table 7 shows the values obtained for the Vector Sum and Consistency Vector, respectively.

To conclude the consistency test, Table 8 shows the values obtained for the arithmetic mean of the Consistency Vector (λ max) column, the Consistency Index (CI), the Random Index (RI) and the Consistency Ratio (CR).

Table 8 - Consistency test

λ max	CI	RI	CR
4,1881	0,062699	0,9	0,0697

Table 5. Comparative matrix of the criteria group

Criteria	Financial	Strategic	Risks (Threat)	Urgency
Financial	1	1	9	3
Strategic	1	1	3	5
Risks (Threat)	1/9	1/3	1	1
Urgency	1/3	1/5	1	1
Total	2,4444	2,5333	14,0000	10,0000

Table 6. Standardization and obtaining criteria weights

Criteria	Financial	Strategic	Risks (Threat)	Urgency	Mean	Weight (%)
Financial	0,4091	0,3947	0,6429	0,3000	0,4367	43,67%
Strategic	0,4091	0,3947	0,2143	0,5000	0,3795	37,95%
Risks (Threat)	0,0455	0,1316	0,0714	0,1000	0,0871	8,71%
Urgency	0,1364	0,0789	0,0714	0,1000	0,0967	9,67%
Total	1,0000	1,0000	1,0000	1,0000	1,0000	100,00%

Table 7. Vector Sum and Consistency Vector

Criteria	Financial	Strategic	Risks (Threat)	Urgency	Weight (%)	Vector Sum	Consistency vector
Financial	1	1	9	3	43,67%	1,8903	4,3289
Strategic	1	1	3	5	37,95%	1,5610	4,1129
Risks (Threat)	1/9	1/3	1	1	8,71%	0,3588	4,1190
Urgency	1/3	1/5	1	1	9,67%	0,4053	4,1916
Total	2,4444	2,5333	14,0000	10,0000	100,00%	4,2154	

After the consistency test, the paired comparison is acceptably inconsistent, since the Consistency Ratio value (0.0697) meets the rule that an acceptable inconsistency must be less than or equal to 0.1.

The next stage of the work was the comparison, in pairs, of the projects in relation to each criterion. The first criterion compared is the Financial, obtaining the Comparison Matrices (Table 9) and Standardization (Table 10), the Consistency Vector (Table 11) and the Consistency Test (Table 12).

Electronic Journal of Management & System
Volume 12, Number 3, 2018, pp.295-310
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Table 9. Matrix Comparative of the group of projects: financial criterion

Financial	Project A	Project B	Project C	Project D
Project A	1	3	2	9
Project B	1/3	1	2	5
Project C	1/2	1/2	1	7
Project D	1/9	1/5	1/7	1
Total	1,9444	4,7000	5,1429	22,0000

Table 10. Standardization and performance of each project: financial criteria

Financial	Project A	Project B	Project C	Project D	Mean	Weight (%)
Project A	0,5143	0,6383	0,3889	0,4091	0,4876	48,76%
Project B	0,1714	0,2128	0,3889	0,2273	0,2501	25,01%
Project C	0,2571	0,1064	0,1944	0,3182	0,2190	21,90%
Project D	0,0571	0,0426	0,0278	0,0455	0,0432	4,32%
Total	1,0000	1,0000	1,0000	1,0000	1,0000	100,00%

Table 11. Vector Sum and Consistency Vector: financial criterion

Financial	Project A	Project B	Project C	Project D	Weight (%)	Vector Sum	Consistency vector
Project A	1	3	2	9	48,76%	2,0651	4,2348
Project B	1/3	1	2	5	25,01%	1,0669	4,2660
Project C	1/2	1/2	1	7	21,90%	0,8905	4,0656
Project D	1/9	1/5	1/7	1	4,32%	0,1787	4,1340
Total	1,9444	4,7000	5,1429	22,0000	100,00%	4,2012	

Table 12. Consistency test: financial criterion

λ max	CI	RI	CR
4,1751	0,058372	0,9	0,0649

The set of paired comparisons of the alternatives according to the financial criterion is acceptably inconsistent due to the value of its Consistency Ratio (0.0649).

The second criterion was Strategic. These are the tables of the Comparison Matrices (Table 13) and the Standardization Table (Table 14), the Consistency Vector (Table 15) and the Consistency Test (Table 16).

Table 13. Comparative matrix of the project group: strategic criterion

Strategic	Project A	Project B	Project C	Project D
Project A	1	2	1/3	1
Project B	1/2	1	1/5	1/3
Project C	3	5	1	3
Project D	1	3	1/3	1
Total	5,5000	11,0000	1,8667	5,3333

Table 14. Standardization and Performance of each project: strategic criterion

Strategic	Project A	Project B	Project C	Project D	Mean	Weight (%)
Project A	0,1818	0,1818	0,1786	0,1875	0,1824	18,24%
Project B	0,0909	0,0909	0,1071	0,0625	0,0879	8,79%
Project C	0,5455	0,4545	0,5357	0,5625	0,5246	52,46%
Project D	0,1818	0,2727	0,1786	0,1875	0,2052	20,52%
Total	1,0000	1,0000	1,0000	1,0000	1,0000	100,00%

Electronic Journal of Management & System
Volume 12, Number 3, 2018, pp.295-310
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Table 15. Vector Sum and Consistency Vector: strategic criterion

Strategic	Project A	Project B	Project C	Project D	Weight (%)	Vector Sum	Consistency vector
Project A	1	2	1/3	1	18,24%	0,7382	4,0463
Project B	1/2	1	1/5	1/3	8,79%	0,3524	4,0104
Project C	3	5	1	3	52,46%	2,1266	4,0542
Project D	1	3	1/3	1	20,52%	0,8260	4,0264
Total	5,5000	11,0000	1,8667	5,3333	100,00%	4,0432	

Table 16. Consistency test: strategic criterion

λ max	CI	RI	CR
4,0343	0,01144	0,9	0,0127

The set of paired comparisons of the alternatives according to the Strategic criterion proves to be acceptably inconsistent due to the value of its Consistency Ratio (0.0127).

The third comparative criterion was Risks (Threat), whose results are presented in the following tables (17-20).

Table 17. Matrix Comparative of the project group: criterion risks (threat)

Risks (Threat)	Project A	Project B	Project C	Project D
Project A	1	1/5	1/3	1/3
Project B	5	1	1	3
Project C	3	1	1	3
Project D	3	1/3	1/3	1
Total	12,0000	2,5333	2,6667	7,3333

Table 18. Normalization and Performance of each project: criterion risks (threat)

Risks (Threat)	Project A	Project B	Project C	Project D	Mean	Weight (%)
Project A	0,0833	0,0789	0,1250	0,0455	0,0832	8,32%
Project B	0,4167	0,3947	0,3750	0,4091	0,3989	39,89%
Project C	0,2500	0,3947	0,3750	0,4091	0,3572	35,72%
Project D	0,2500	0,1316	0,1250	0,1364	0,1607	16,07%
Total	1,0000	1,0000	1,0000	1,0000	1,0000	100,00%

Table 19. Vector Sum and Consistency Vector: criterion risks (threat)

Risks (Threat)	Project A	Project B	Project C	Project D	Weight (%)	Vector Sum	Consistency vector
Project A	1	1/5	1/3	1/3	8,32%	0,3356	4,0345
Project B	5	1	1	3	39,89%	1,6542	4,1472
Project C	3	1	1	3	35,72%	1,4878	4,1652
Project D	3	1/3	1/3	1	16,07%	0,6623	4,1205
Total	12,0000	2,5333	2,6667	7,3333	100,00%	4,1400	

Table 20. Consistency test: criterion risks (threat)

λ max	CI	RI	CR
4,1169	0,038952	0,9	0,0433

The set of paired comparisons of the alternatives according to the criteria Risk (Threat) is acceptably inconsistent due to the value of its Consistency Ratio (0.0433).

The last criterion compared was the one of Urgency, as it is verified in the tables 22-24.

Electronic Journal of Management & System
Volume 12, Number 3, 2018, pp.295-310
DOI: 10.20985/1980-5160.2018.v13n3.1309

Table 21. Comparative matrix of the project group: urgency criterion

Urgency	Project A	Project B	Project C	Project D
Project A	1	1/9	3	3
Project B	9	1	9	9
Project C	1/3	1/9	1	1
Project D	1/3	1/9	1	1
Total	10,6667	1,3333	14,0000	14,0000

Table 22. Standardization and Performance of each project: urgency criterion

Urgency	Project A	Project B	Project C	Project D	Mean	Weight (%)
Project A	0,0938	0,0833	0,2143	0,2143	0,1514	15,14%
Project B	0,8438	0,7500	0,6429	0,6429	0,7199	71,99%
Project C	0,0313	0,0833	0,0714	0,0714	0,0644	6,44%
Project D	0,0313	0,0833	0,0714	0,0714	0,0644	6,44%
Total	1,0000	1,0000	1,0000	1,0000	1,0000	100,00%

Table 23. Vector Sum and Consistency Vector: urgency criterion

Urgency	Project A	Project B	Project C	Project D	Weight (%)	Vector Sum	Consistency vector
Project A	1	1/9	3	3	15,14%	0,6176	4,0786
Project B	9	1	9	9	71,99%	3,2411	4,5023
Project C	1/3	1/9	1	1	6,44%	0,2592	4,0270
Project D	1/3	1/9	1	1	6,44%	0,2592	4,0270
Total	10,6667	1,3333	14,0000	14,0000	100,00%	4,3770	

Table 24. Consistency test: criterion of urgency

λ max	CI	RI	CR
4,1587	0,052908	0,9	0,0588

The set of paired comparisons of the alternatives according to the Urgency criterion is acceptably inconsistent due to the value of its Consistency Ratio (0.0588).

Table 25, Decision Matrix shows the weight assigned to each criterion, the performance of each project in relation to it, and the result of the matrix multiplication between the weight of each criterion and the percentage of performance of each project.

Table 25. Final performance of each project

	Financial	Strategic	Risks (Threat)	Urgency	Results
Weights	43,67%	37,95%	8,71%	9,67%	
Project A	48,76%	18,24%	8,32%	15,14%	30,41%
Project B	25,01%	8,79%	39,89%	71,99%	24,69%
Project C	21,90%	52,46%	35,72%	6,44%	33,21%
Project D	4,32%	20,52%	16,07%	6,44%	11,70%
Total	100,00%	100,00%	100,00%	100,00%	100,00%

The project with the best performance in the application of the AHP Model is Project C, with 33.21%; followed by Project A, with 30.41%; Project B, with 24.69%; and Project D, with 11.70%. The next item shows the Sensitivity Analysis of the results.

Electronic Journal of Management & System
Volume 12, Number 3, 2018, pp.295-310
DOI: 10.20985/1980-5160.2018.v13n3.1309

4.2. Sensitivity analysis

The type of Sensitivity Analysis used in this article was that of changes in the relative weights of the criteria, which suggests that all possibilities of comparisons are exhausted. However, in the case of this work, three simulations were performed, varying the values of the Fundamental Scale assigned to the comparisons. In this way, the Sensitivity Analysis can test any variations in the decision maker's evaluation of the matched comparisons between the criteria. The results are described below.

1st Simulation

The comparison between the criteria Risk (Threat) and Urgency, both initially assessed with the same importance, undergoes a small change. In this simulation, the Urgency criterion now has very small importance on the Strategic criterion (equivalent to the value 2 in the Fundamental Scale, in which case, as the comparison is the inverse, the value will be 1/2). The other comparisons remained the same. Table 26 shows the values of the previous comparisons with values of this 1st simulation.

Table 29 shows the result of the 1st simulation. With the change in relevance between the Risk (Threat) and Urgency criteria, there is a small change in the results. Project C continues to perform best in the application of the AHP Model, even reducing its previous percentage from 33.21% to 32.86%, and Project A decreases its percentage from 30.41% to 30.28%.

Table 26. Evaluation Variations for Sensitivity Analysis

Comparisons	Original value	Variations
Financial – Strategic	1	1
Financial – Risks (Threat)	9	9
Financial – Urgency	3	3
Strategic – Risks (Threat)	3	3
Strategic – Urgency	5	5
Risks (Threat) – Urgency	1	1/2

Table 27 shows the new Comparative Matrix obtained through the simulations.

Table 27. Comparative matrix of the criteria group

Criteria	Financial	Strategic	Risks (Threat)	Urgency
Financial	1	1	9	3
Strategic	1	1	3	5
Risks (Threat)	1/9	1/3	1	1/2
Urgency	1/3	1/5	2	1
Total	2,4444	2,5333	15,0000	9,5000

Table 28 shows the consistency test result.

Table 28. Consistency test

λ max	CI	RI	CR
4,1988	0,066269	0,9	0,0736

Table 29. Final performance of each project

	Financial	Strategic	Risks (Threat)	Urgency	Results
Weights	42,99%	38,25%	7,41%	11,35%	
Project A	48,76%	18,24%	8,32%	15,14%	30,28%
Project B	25,01%	8,79%	39,89%	71,99%	25,24%
Project C	21,90%	52,46%	35,72%	6,44%	32,86%
Project D	4,32%	20,52%	16,07%	6,44%	11,63%
Total	100,00%	100,00%	100,00%	100,00%	100,00%

2nd Simulation

The comparison between the Financial and Risks (Threat) criteria, where the Financial criterion has absolute importance on Risks (Threat), undergoes a small change. In this simulation, the Financial criterion is very important on the Strategic criterion (equivalent to the value 7 in the Fundamental Scale). The other comparisons remain the same.

Tables 30, 31 and 32 show, respectively, the values of the previous comparisons and the new values of this 2nd simulation; the new comparative matrix obtained through the simulations and the consistency test result.

Electronic Journal of Management & System
Volume 12, Number 3, 2018, pp.295-310
DOI: 10.20985/1980-5160.2018.v13n3.1309

Table 30. Evaluation Variations for Sensitivity Analysis

Comparisons	Original value	Variations
Financial – Strategic	1	1
Financial – Risks (Threat)	9	7
Financial – Urgency	3	3
Strategic – Risks (Threat)	3	3
Strategic – Urgency	5	5
Risks (Threat) – Urgency	1	1

Table 31. Comparative matrix of the criteria group

Criteria	Financial	Strategic	Risks (Threat)	Urgency
Financial	1	1	7	3
Strategic	1	1	3	5
Risks (Threat)	1/7	1/3	1	1
Urgency	1/3	1/5	1	1
Total	2,4762	2,5333	12,0000	10,0000

Table 32. Consistency test

λ max	CI	RI	CR
4.124	0.041328	0.9	0.0459

Table 33 shows the result of the 2nd simulation. With the change in terms of relevance between the Financial and Risk (Threat) criteria, there is a small change in the results. Project C again has the best performance in applying the AHP Model, increasing its original comparison percentage from 33, 21% to 33.48%, and Project A returns to second place, reducing its percentage from 30.41% to 29.84%.

3rd Simulation

The comparison between the Strategic and Risk (Threat) criteria, where the Strategic criterion has little importance on Risks (Threat), has undergone a minor change. In this simulation the Strategic criterion now has very great importance on the Strategic criterion (equivalent to the value 7 in the Fundamental Scale). The other comparisons remain the same.

Tables 34, 35 and 36 show, respectively, the values of the previous comparisons and the new values of this 3rd simulation, the new comparative matrix obtained through the simulations and the consistency test result.

Table 33. Final Performance of each Project

	Financial	Strategic	Risks (Threat)	Urgency	Results
Weights	42,05%	38,71%	9,32%	9,92%	
Project A	48,76%	18,24%	8,32%	15,14%	29,84%
Project B	25,01%	8,79%	39,89%	71,99%	24,78%
Project C	21,90%	52,46%	35,72%	6,44%	33,48%
Project D	4,32%	20,52%	16,07%	6,44%	11,90%
Total	100,00%	100,00%	100,00%	100,00%	100,00%

Table 34. Evaluation Variations for Sensitivity Analysis

Comparisons	Original value	Variations
Financial – Strategic	1	1
Financial – Risks (Threat)	9	9
Financial – Urgency	3	3
Strategic – Risks (Threat)	3	7
Strategic – Urgency	5	5
Risks (Threat) – Urgency	1	1

Electronic Journal of Management & System
Volume 12, Number 3, 2018, pp.295-310
DOI: 10.20985/1980-5160.2018.v13n3.1309

Table 35. Comparative matrix of the criteria group

Criteria	Financial	Strategic	Risks (Threat)	Urgency
Financial	1	1	9	3
Strategic	1	1	7	5
Risks (Threat)	1/9	1/7	1	1
Urgency	1/3	1/5	1	1
Total	2,4444	2,3429	18,0000	10,0000

Table 36. Consistency test

	CI	RI	CR
4.1054	0.035119	0.9	0,0390

Table 37 shows the result of the 3rd simulation. With the change in relevance between the Strategic and Risk (Threat) criteria, there is a small change in the results. Project C again had the best performance in applying the AHP Model, increasing its original comparison percentage from 33, 21% to 34.52%, and Project A returned to second place, reducing its percentage from 30.41% to 29.78%.

After the three simulations were carried out, Table 38 was elaborated, comparing the original weights with the simulated weights, and Table 39, with the comparison of the performance of the projects.

After analyzing the performance comparison of the projects, it can be seen that, regardless of the changes in importance of the criteria performed in the simulations, Project C maintains the best performance, proving to be a robust choice, allowing the decision maker to be more secure in relation to his choice.

Table 37. Final performance of each project

	Financial	Strategic	Risks (Threat)	Urgency	Results
Weights	40,90%	43,12%	6,55%	9,43%	
Project A	48,76%	18,24%	8,32%	15,14%	29,78%
Project B	25,01%	8,79%	39,89%	71,99%	23,42%
Project C	21,90%	52,46%	35,72%	6,44%	34,52%
Project D	4,32%	20,52%	16,07%	6,44%	12,27%
Total	100,00%	100,00%	100,00%	100,00%	100,00%

Table 38. Comparison of weights obtained by simulation

	Original weight	1st Simulation	2nd Simulation	3nd Simulation
Financial	43,67%	42,99%	42,05%	40,90%
Strategic	37,95%	38,25%	38,71%	43,12%
Risks (Threat)	8,71%	7,41%	9,32%	6,55%
Urgency	9,67%	11,35%	9,92%	9,43%

Table 39. Project Performance Comparison

	Original weight	1st Simulation	2nd Simulation	3nd Simulation
Project A	30,41%	30,28%	29,84%	29,78%
Project B	24,69%	25,24%	24,78%	23,42%
Project C	33,21%	32,86%	33,48%	34,52%
Project D	11,70%	11,63%	11,90%	12,27%

5. FINAL CONSIDERATIONS

This article describes a research that is characterized as applied, quantitative and exploratory, bringing in its development the application of a well-known mathematical-psychological model - the AHP - and discussions pertinent to its use, with the aid of an easily available spreadsheet, in a problem of theoretical decision, adapted from a real case.

Electronic Journal of Management & System
Volume 12, Number 3, 2018, pp.295-310
DOI: 10.20985/1980-5160.2018.v13n3.1309

All calculations were performed with Microsoft® Office Excel software, which is sufficient and easy to use for the application of the AHP model. For the application example described in this article a single worksheet was used, with cells containing simple formulas, according to the step-by--step proposed by Saaty.

A common mistake made by novice decision makers is to try to solve a given decision problem by means of commercially available software, without knowing the analytical model embedded in it, mainly from a technical point of view. In spite of the practicality of the use of specialized programs, in order to present an alternative choice, this article made use of an electronic spreadsheet, easily available and also easy to implement, in order to provide a more didactic and accessible approach to anyone who wants to use AHP as a model.

In the AHP, the vector ϖ and relative priority vectors generated by the pairwise comparison of the judgments are ideally obtained by the algebraic calculation of the right eigenvector associated with the maximum eigenvalue of the Pairwise Comparison Matrix. However, Saaty himself proposed approximate forms, such as the processes of "calculation of the average of the normalized values" and the geometric mean method. The process of "calculation of the mean of the normalized values", used in this article is much more practical and has extremely close results to those obtained with the algebraic calculation of the matrix eigenvector, as it is perfectly adequate to the type of precision required in problems of the type discussed.

All the references of the real case were suppressed, thus protecting the identity of the company from which the case studied originated, as well as the manager who answered the paired comparisons questionnaire.

Of course, the present article suffers from limitations that are common to long conceptual researches that are synthesized in a few lines, since the deepening of the many aspects related to the AHP would escape the scope of the article. However, from its exploratory character, it is possible to deploy proposals for future research, among which the deepening of the use of the studied model and the analysis presented.

While PPM - the result of negotiation, human aspects and strategic analysis - has gained considerable relevance in the development of management systems - as it is an activity that links the strategic objectives of companies with their project management routines - its implementation is not a trivial task; therefore, the use of AHP is proposed in this article to assist in this type of decision making. Thus, the work developed in this article ratifies that it is possible to use a Multicriteria Model of Decision Support, the AHP, as an aid to PPM.

Thus, the feasibility of using the AHP for the Project Portfolio Management modeling is emphasized, highlighting the importance and the benefits in the AHP of the Consistency Analysis, often disregarded, and the Sensitivity Analysis, allowing decision-makers not only to determine and justify their decision, but to learn and perfect their decision-making process.

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