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Prioritization of R&D projects in the aerospace sector: AHP method with ratings

Abstract: *The prioritization of R&D projects in the Aerospace Sector is considered a complex problem because it involves qualitative and quantitative issues that are frequently conflicting. This paper aimed to apply the AHP (Analytic Hierarchy Process) method with ratings to select projects of R&D in a Brazilian aerospace institution, Department of Science and Aerospace Technology (DCTA). The results showed that using ratings is appropriate when there is a great quantity of projects, since it reduces the judgments required to the decision maker.*
Keywords: *Prioritization of Research and Development Projects (R&D), AHP, Ratings.*

INTRODUCTION

Nowadays, most of organizations have been facing difficulties regarding the evaluation of projects prioritization. These difficulties are due to the complexity of the problems analyzed before a decision making.

In literature, the selection of R&D projects is considered a complex problem because it involves qualitative and quantitative issues that are frequently conflicting. It also presents risks and uncertainties, as well as the necessity of balancing important factors, interdependence between projects and a great number of feasible portfolios (Ghasemzadeh and Archer, 2000).

In order to deal with the complexity of decision making problems with many criteria, some methods to support it can be used. These methods aim to clarify the decision-making process, assisting and guiding the decision maker (or makers) regarding structure, evaluation and alternatives of the problem (Gomes, Gomes and Almeida, 2006).

This work aimed to apply the Analytic Hierarchy Process (AHP) method with ratings to select aerospace R&D projects of a sector in a Brazilian aerospace organization. Using ratings means categorizing previously defined criteria and/or subcriteria in order to classify alternatives. This procedure is suitable when there are many projects, since this procedure reduces the number of judgment required to the decision maker.

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As an example, we describe the application exercise of the Department of Science and Aerospace Technology (DCTA), São José dos Campos, São Paulo, Brazil.

This work is presented as follows: first, we describe the prioritization of R&D projects and the Analytic Hierarchy Process (AHP) method with ratings; next, we explain the application of the proposed method to select projects of R&D aerospace; finally, we present the final considerations.

THEORETICAL REFERENCE

Prioritization of R&D projects

According to Weisz (2006), R&D projects are risky and require long-term investments.

Selecting the best R&D projects means to choose projects whose responsible organization will support them financially.

According to Meade and Presley (2002), the selection of R&D projects is frequently based on financial criteria such as Net Present Value (NPV) and Internal Rate of Return (IRR). Despite the importance of such criteria, the authors claim that once the decisions must be strategically considered, other criteria must be taken into account, even though it is difficult to quantify.

The R&D selection and prioritization is performed in a decision-making environment depicted by multicriteria that allow the use of Multiple-Criteria Decision-Making methods (MCDM), including the Analytic Hierarchy Process (AHP) method using ratings.

Analytic Hierarchy Process using ratings

Developed by Thomas L. Saaty in 1980, the AHP is one of the first methods developed in an environment of discrete multicriteria decision. The AHP method divides the problem into hierarchic levels, which makes its comprehension and evaluation easier and clearly determines a global action for each alternative by the value synthesis of the decision makers, prioritizing or classifying them after finalizing the method.

According to Saaty (2008), to make a decision in an structured way and generate priorities, we need to decompose the decision into the following steps: 1) define the problem and determine the kind of knowledge sought, 2) structure the decision hierarchy starting from the top with the goal of the decision, and of the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives), 3) construct a set of pairwise comparison matrices. Each element in upper levels is used to compare the elements of the immediately lower level with respect to it and, 4) use of priorities obtained from the comparisons to weigh the priorities in the immediately lower level. This must be performed for each element. Then for each element in the lower level, the weighed values are added and the overall or global priority is obtained. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom levels are obtained. The AHP method will not be detailed. For further details see Saaty (1980).

Step 1: Define the problem and determine the kind of knowledge sought

In this step the goal of the decision process is decided, the criteria and subcriteria are identified based on the decision maker's values and beliefs, as well as the alternatives of decision to solve the problem.

Step 2: Structure the decision hierarchy

The hierarchy structure is build aiming at the top decision, followed by intermediate levels (the criteria on which the posterior elements depend) to the inferior level (which is usually a set of alternatives). Based on a representation of a decision problem in a hierarchic structure, the decision maker builds the pairwise matrix of the elements.

Step 3: Construct a set of pairwise comparison matrices

Pairwise comparison matrices are built from results between elements, considering the Saaty Fundamental Scale (Saaty, 1980). Each element in the upper level is used to compare the elements of an immediate inferior level with respect to the former. That is, the alternatives are compared with respect to the subcriteria, the subcriteria are compared with respect to the criteria and these criteria are compared with respect to the global objective.

In this step, the verification of the pair comparison judgments consistency is also made.

Step 4: Use the priorities obtained from the comparisons to weigh the priorities in the immediately lower level

The last step refers to the obtainment of elements priorities (called eigenvector or priority vectors) to generate the final values of the alternative priorities. The local priorities obtained from the comparisons are used to ponder the priorities of the immediately lower level for each element. Thus, pondered values are added for each element in lower levels, and the total or global priority is obtained. The total priorities of the alternatives are found by multiplying their local priorities by the global alternatives of all criteria and respective subcriteria, resulting in the addition of the results to all alternatives. Therefore, we obtain the priority ranking of alternatives and also of the criteria and subcriteria.

Ratings (absolute measurement)

Duarte Júnior (2005) defines ratings as a set of intensity levels (or categories) that serves as a base to evaluate the performance of the alternatives in terms of each criterion and/or subcriterion. The categories that form the ratings must be clearly defined, in the less ambiguous way as possible, to adequately describe the criterion/subcriteria. The rating is considered suitable as the decision makers consider it an appropriate tool to evaluate alternatives.

Figure 1 shows the hierarchy structure from the rating mode. The hierarchy begins with the global objective. The criteria are at the second level. The categories associated to the subcriteria are at the last level.

The structure with ratings differs from the traditional AHP (relative measurement), because in the last level the alternatives are not found. The evaluation is performed by intensity levels (categories) attributed to each subcriteria related to each alternative, instead of evaluating the alternatives by pairwise comparisons.

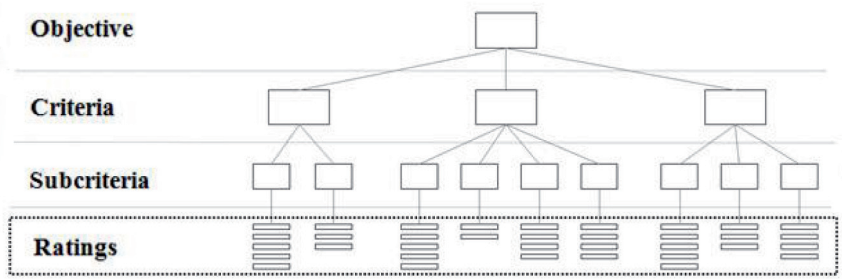

Figure 1: Hierarchy structure – ratings model.

To establish the relative importance of these categories (obtaining priority vectors), the specialist's (or specialists') values/opinions are incorporated to the rating system.

Duarte Júnior (2005) presents proposals to obtain numerical values of ratings (priority vectors) such as pairwise comparison process of AHP method. In this proposal, the rating pairwise comparisons are performed to define the priorities of each criterion (or subcriterion).

Saaty (1987, 2006, 2008) suggests that when working with ratings the priority vectors obtained are idealised, that is, the best category receives the value 1 and the others must be proportionally smaller. The synthesis of results, that is, the alternatives of final priorities are found by adding the values referring to the multiplication between the properties of each category and the global priorities of the criteria/subcriteria in these categories.

The main advantage of using ratings is to decrease the number of comparisons necessary when there are a large number of alternatives. Besides, when using absolute measurement (ratings), it does not matter how many new alternatives are introduced, or old ones are excluded because there is no inversion of the alternatives ranking.

The software Expert Choice and SuperDecisions include, besides the traditional AHP, the AHP with ratings (absolute measurement). In this paper, a brief description of AHP with ratings is presented and the application exercise used the software SuperDecisions, developed by Creative Decisions Foundation.

AHP APPLICATION WITH RATINGS: SELECT PROJECTS OF R&D AEROSPACE (DCTA)

The application of the AHP method in this paper is based on the study case of Lima and Damiani, 2010.

Step 1: Define the problem and determine the kind of knowledge sought

Lima and Damiani (2010) present a proposal of problem structuring to prioritize the aerospace R&D projects. The authors reported that the goal of this proposal was to suggest an analytical structure that could enable a R&D institution acting in the aerospace sector to identify and structure their own decision criteria in relation to the selection process of R&D processes, with a wide range of possibilities.

The study case of Lima and Damiani (2010) has been performed in the Department of Science and Aerospace Technology (DCTA). This organization, founded in 1953, focus the progress of technical-scientific activities related to the aerospace education, research and development that are interesting to the Ministry of Defense.

As R&D projects prioritization is a complex decision-making problem, the authors preferred structuring the problem through a tool of cognitive maps, employing the constructivist paradigm of decision support.

Therefore, the purpose of this work was to select aerospace R&D projects, in association with the organization strategies. This paper is based on the problem structuring of Lima and Damiani (2010). The MCDM method chosen for this evaluation is the AHP using ratings. The decision maker is the same as Lima and Damiani (2010).

The criteria are: Potential to generate Innovation (PI), Technological Maturity (TM), Duality (D), Operational Alignment (OA), Means Availability (MA), Risk Response (RR), and Opportune Attendance (OpA). The MA criterion presents the subcriteria: Finance Resources (FR), Human Capacitation (HC), and Infrastructure (IS). More details and further explanation of the criteria and subcriteria are found in Lima and Damiani (2010).

All criteria and subcriteria were considered independent, as the AHP method indicates. The definition of the ratings for problem criteria and subcriteria follows Table 1.

The alternatives selected by the organization are five big R&D projects named: Project A, Project B, Project C, Project D and Project E. Three of these projects are real projects of the institution.

Step 2: Structure the decision hierarchy

Figure 2 presents the hierarchy structure for the problem of aerospace R&D projects selection. The first hierarchic level is the global objective: "prioritize projects". On the second level, the main aspects that the decision maker has to consider when performing the prioritization of R&D projects are Strategic Alignment (SA) and Realization Potential (RP). On the third level, the criteria and, on the fourth level, the subcriteria. In the last level, the categories (Table 1) that describe the associated criteria and subcriteria are found.

According to the decision maker, this hierarchy is used to evaluate small and big projects. The AS aspects are more important when bigger projects are evaluated.

After the problem is formulated, and the hierarchy is built and validated, the judgment process is started when the

Table 1: Definition of the ratings for the criteria and subcriteria

Criteria and subcriteria	Ratings
Potential to generate Innovation (PI)	PI1- is involved in the industry since its inception. PI2- has the potential to involve industry. PI3- there is no industrial interest with regard to the project.
Technological Maturity (TM)	TM1- the project attempts an elevation of the current level of technological maturity. TM2- the project strengthens the current level of technological maturity. TM3- the project has no effect on the current level of technological maturity.
Duality (D)	D1- it has the potential to generate civilian and military application. D2- it has the potential to generate for civilian use only. D3- it has the potential to generate only a military application.
Operational Alignment (OA)	OA1- responds to a formalized operational need. OA2- it serves an operational need not formalized. OA3- there is a possibility of operational implementation. OA4- has not operational application.
Means Availability (MA)	
MA1. Finance Resources (FR)	FR1- has resources available (officially announced). FR2- has potential for features (has promises) FR3- it is necessary to obtain resources management (persuasion). FR4- there are reasons to believe that resources are not available.
MA2. Human Capacitation (HC)	HC1- there is availability of trained human resources for the project. HC2- there is trained human resources, but availability must be shared with other projects. HC3- there is availability of staff, but requiring training. HC4- there is no available and qualified human resources for the project.
MA3.Infrastructure (IS)	IS1- OM (military organization) already has the infrastructure to serve the project. IS2- OM has partial infrastructure to support the project. IS3- there is no infrastructure in the OM, but availability is feasible. IS4- there is a great difficulty in providing OM infrastructure that meets the project.
Risk Response (RR)	RR1- the risk analysis shows that the project presents no significant risk. RR2- the risk analysis shows that they can be avoided by mitigation measures. RR3- the risk analysis provides risk mitigation difficult
Opportune Attendance (OpA)	OpA1- the period planned to exceed customer's expectations. OpA2- the period planned to meet customer's expectations. OpA3- the term planned partially meets the customer's expectations. OpA4- the planned period is not satisfying for the customer's expectations.

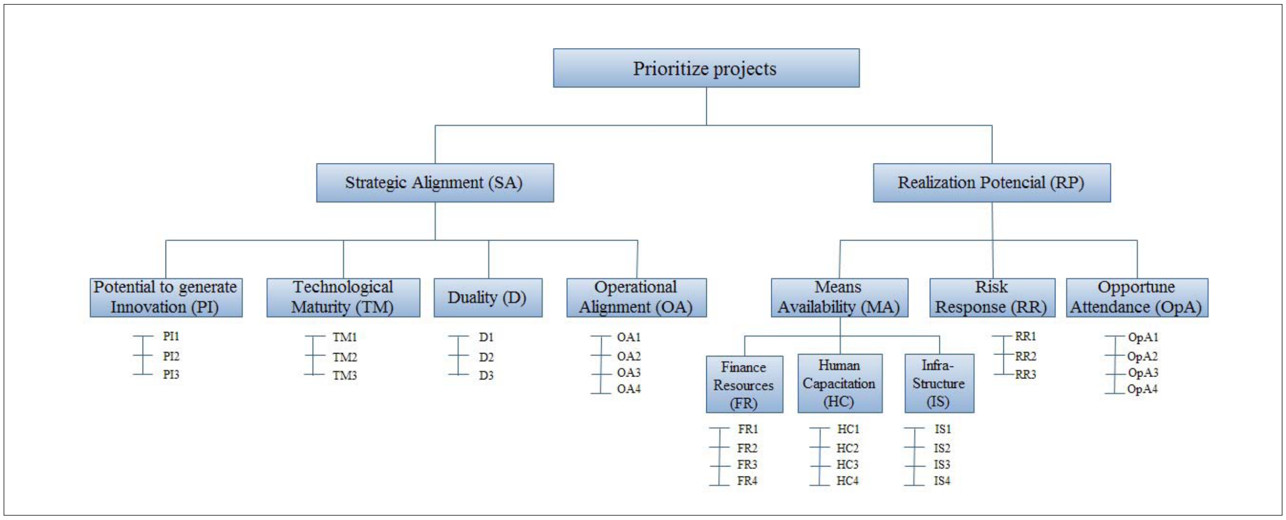

Figure 2: Hierarchy structure for the problem.

decision makers express their preferences through the pairwise comparison matrices of the criteria/subcriteria and ratings.

Step 3: Construct a set of pairwise comparison matrices

In this step, the decision matrix is formed in order to obtain the values of importance of the criteria, subcriteria and ratings. These values attribution is based on Saaty's Fundamental Scale (Saaty, 1980). For each decision, the Consistency Ratio (CR) is calculated.

The priorities of each category are determined by using the pairwise comparison process of AHP method.

The decision matrices are shown as follows. Table 2 presents decision matrices of judgments of the main aspects that the decision maker considers when prioritizing the R&D projects in relation to the objective.

Table 3 presents the decision matrix of judgments between the criteria with respect to and SA aspect.

Table 4 presents the decision matrix of judgments between the criteria with respect to RP aspect.

Table 5 presents the decision matrix of judgments between the subcriteria with respect to and Means Availability (MA).

In order to obtain the numerical values of ratings, a comparison matrix between the rating intensity levels was built. Through this matrix, the relative importance among levels of intensity was found, calculating the

Table 2: Decision matrix of judgments of the main aspects with respect to the objective

Objective	**SA**	**RP**	**Priorities**	
SA	1	3/2	0.6	CR=0.0
RP	2/3	1	0.4	

Table 3: Decision matrix of judgments of the criteria with respect to the SA aspect

SA	**PI**	**TM**	**D**	**OA**	**Priorities**	
PI	1	1	3	3	0.367	CR=0.0039
TM		1	4	3	0.396	
D			1	1	0.114	
OA				1	0.122	

Table 4: Decision matrix of judgments for criteria with respect to the RP aspect.

RP	**MA**	**RR**	**OpA**	**Priorities**	
MA	1	4	3/2	0.532	
RR		1	1/2	0.146	CR=0.0089
OpA			1	0.322	

Table 5: Decision matrix of judgments for the subcriteria with respect to Means Availability (MA).

MA	**FR**	**HC**	**IS**	**Priorities**	
FR	1	1	1	0.337	
HC		1	3	0.457	CR=0.0904
IS			1	0.207	

self-vector that represents the "performance" for each intensity level.

The rating numerical values for the criteria and subcriteria are presented in tables. These ratings must be idealised before the alternative final priorities calculation.

Table 6 presents a decision matrix of comparisons for the rating levels of intensity with respect to the Potential of Generating Innovation (PI).

Table 7 presents a decision matrix of comparisons for the ratings levels of intensity with respect to the criteria of Technological Maturity (TM).

Table 8 presents a decision matrix of comparisons for the rating levels of intensity with respect to the criteria of Duality (D).

Table 9 presents a decision matrix of comparisons for the rating levels of intensity with respect to the criteria of Operational Alignment (OA).

Table 6: Decision matrix of comparisons for the rating levels of intensity with respect to the Potential of generating Innovation (PI) (CR=0.0311)

PI	PI1	PI2	PI3	Priorities	Idealised priorities
PI1	1	3	7	0.659	1.000
PI2		1	4	0.263	0.399
PI3			1	0.079	0.119

Table 7: Decision matrix of comparisons for the rating levels of intensity with respect to the criteria of Technological Maturity (TM) (CR=0.0824)

TM	TM1	TM2	TM3	Priorities	Idealised priorities
TM1	1	3	5	0.627	1.000
TM2		1	4	0.280	0.446
TM3			1	0.094	0.149

Table 8: Decision matrix of comparisons for the rating levels of intensity with respect to the criteria of Duality (D) (CR=0.0516)

D	D1	D2	D3	Priorities	Idealised priorities
D1	1	1	2	0.413	1.000
D2		1	1	0.327	0.794
D3			1	0.260	0.630

Table 10 presents a decision matrix of comparisons for the rating levels of intensity with respect to the subcriteria of Finance Resources (FR).

Table 11 presents a decision matrix of comparisons for the ratings levels of intensity with respect to the subcriteria of Human Capacitation (HC).

Table 12 presents a decision matrix of comparisons for the rating levels of intensity with respect to the subcriteria of Infrastructure (IS).

Table 13 presents a decision matrix of comparisons for the rating levels of intensity with respect to the criteria of Risk Response (RR).

Table 9: Decision matrix of comparisons for the rating levels of intensity with respect to the criteria of Operational Alignment (OA) (CR=0.0290)

OA	OA1	OA2	OA3	OA4	Priorities	Idealised priorities
OA1	1	1	2	7	0.412	1.000
OA2		1	1	3	0.282	0.684
OA3			1	3	0.231	0.562
OA4				1	0.075	0.181

Table 10: Decision matrix of comparisons for the ratings levels of intensity with respect to the subcriteria of Finance Resources (FR) (CR=0.0188)

FR	FR1	FR2	FR3	FR4	Priorities	Idealised priorities
FR1	1	2	4	7	0.536	1.000
FR2		1	1	3	0.215	0.401
FR3			1	3	0.181	0.339
FR4				1	0.068	0.128

Table 11: Decision matrix of comparisons for the rating levels of intensity with respect to the subcriteria of Human Capacitation (HC) (CR=0.0638)

HC	HC1	HC2	HC3	HC4	Priorities	Idealised priorities
HC1	1	3	4	7	0.542	1.000
HC2		1	3	5	0.269	0.496
HC3			1	4	0.137	0.252
HC4				1	0.052	0.096

Table 12: Decision matrix of comparisons for the rating levels of intensity with respect to the subcriteria of Infrastructure (IS) (CR=0.0030)

IE	IE1	IE2	IE3	IE4	Priorities	Idealised priorities
IE1	1	2	3	9	0.507	1.000
IE2		1	2	4	0.280	0.552
IE3			1	3	0.157	0.310
IE4				1	0.055	0.108

Table 13: Decision matrix of comparisons for the rating levels of intensity with respect to the criteria of Risk Response (RR) (CR=0.0136)

RR	RR1	RR2	RR3	Priorities	Idealised priorities
RR1	1	2	7	0.592	1.000
RR2		1	5	0.333	0.563
RR3			1	0.075	0.127

Table 14 presents a decision matrix of comparisons for the rating levels of intensity with respect to the criteria of Opportune Attendance (OpA).

The judgment consistency was made through pairwise matrices. All the presented CR (Consistency Ratio) less than 10% (or 0,1) indicate the judgment coherence of the decision makers.

Step 4: Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below

Based on the vectors generated by the method, the local priorities of the criteria and subcriteria were obtained.

Figure 3 presents the global priorities of the criteria and subcriteria (in parentheses) and the numerical values of the ratings (idealised) for criteria and subcriteria.

Table 15 presents the classification of alternatives (projects) in the criteria and subcriteria ratings corresponding to the categories (Fig. 3).

Table 14: Decision matrix of comparisons for the ratings levels of intensity with respect to the criteria of Opportune Attendance (OpA) (CR=0.0354)

OpA	OpA1	OpA2	OpA3	OpA4	Priorities	Idealised priorities
OpA1	1	1	4	7	0.444	1.000
OpA2		1	2	3	0.338	0.761
OpA3			1	4	0.162	0.365
OpA4				1	0.055	0.125

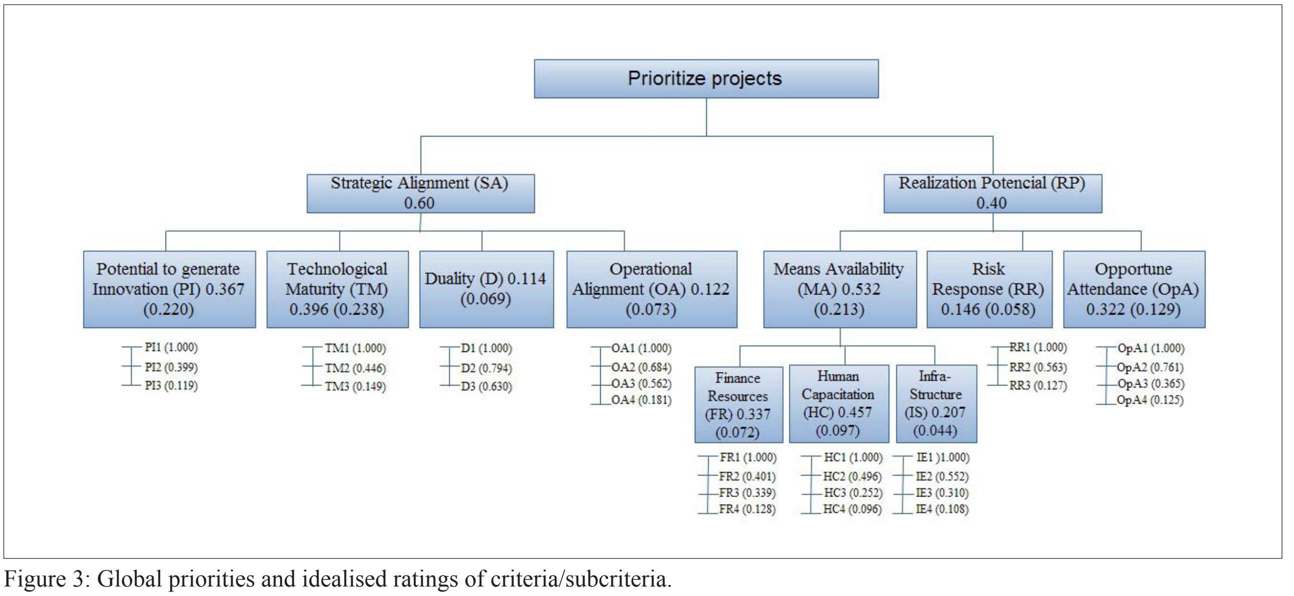

Figure 3: Global priorities and idealised ratings of criteria/subcriteria.

Table 16 presents a final punctuation for each Project. It is calculated by adding the products between the global priorities of the criteria and subcriteria and the ratings values for each alternative, thus obtaining the "Totals" column which normalized presents the final punctuation ("Final priorities"). For example, for Project A, we have:

Totals_Project_A = (0.220 x 1.000) + (0.238 x 1.000) + (0.069 x 1.000) + (0.073 x 0.684) + (0.072 x 0.401) + (0.097x 0.252) + (0.044 x 0.310) + (0.058 x 1.000) + (0.129 x 0.365) = 0.749

Table 17 presents the final priorities (in graphics) for the alternatives. The columns "Total" and "Normal" are equivalent to the total and final priorities of Table 16, respectively. The column "Ideal" is obtained by dividing all elements of "Total" by its highest value.

In this case, the best evaluated project is Project D, followed by Project B, Project E, Project A and Project C.

A sensitivity analysis would be required to study how to choose the project D over project B, since

Table 15: Classification of the alternatives in ratings

Criteria/Subcriteria	Ratings				
	Project A	**Project B**	**Project C**	**Project D**	**Project E**
PI	PI1	PI1	PI2	PI1	PI1
TM	TM1	TM1	TM1	TM1	TM1
D	D1	D1	D1	D1	D1
OA	OA2	OA2	OA3	OA1	OA1
FR	FR2	FR1	FR1	FR1	FR1
HC	HC3	HC1	HC2	HC2	HC2
IS	IS3	IS1	IS2	IS2	IS3
RR	RR1	RR2	RR2	RR2	RR3
OpA	OpA3	OpA3	OpA3	OpA2	OpA4

Table 16: Final priorities of the alternatives

Alternatives	PI (0.220)	TM (0.238)	D (0.069)	OA (0.073)	FR (0.072)	HC (0.097)	IS (0.044)	RR (0.058)	OpA (0.129)	Total	Final Priorities
Project A	1.000	1.000	1.000	0.684	0.401	0.252	0.310	1.000	0.365	0.749	0.192
Project B	1.000	1.000	1.000	0.684	1.000	1.000	1.000	0.563	0.365	0.869	0.222
Project C	0.399	1.000	1.000	0.562	1.000	0.496	0.552	0.563	0.365	0.659	0.169
Project D	1.000	1.000	1.000	1.000	1.000	0.496	0.552	0.563	0.761	0.875	0.224
Project E	1.000	1.000	1.000	1.000	1.000	0.496	0.310	0.127	0.125	0.757	0.194

Table 17: Ranking of the alternatives

Graphic	Ratings alternatives	Total	Ideal	Normal	Ranking
	Project A	0.7492	0.8562	0.1916	4
	Project B	0.8694	0.9937	0.2224	2
	Project C	0.6593	0.7535	0.1686	5
	Project D	0.8749	1.0000	0.2238	1
	Project E	0.7569	0.8651	0.1936	3

they have similar evaluations. Moreover, it is worth noting that the use of AHP method does not allow analyzing the portfolio projects with respect to resource constraints. In this case, one would have to use a hybrid methodology, such as AHP method and integer programming.

For this problem, 55 comparisons were performed, as shown in Table 18.

Table 18: Comparative study between AHP relative model and AHP rating model

Number of alternatives	Number of comparisons	
	AHP relative model	AHP rating model
3	40	55
5	103	55
9	337	55
20	1723	55

However, in comparison with the AHP relative model, as the alternative number increases, the number of comparisons increases considerably, while in AHP rating model, it remains the same.

It is known that, depending on the complexity of the problem, the use of AHP ratings model is advantageous, because it can significantly reduce time and effort in the decision-making process.

FINAL CONSIDERATIONS

The aim of this paper was to present a proposal of project selection and prioritization, through Multiple-Criteria Decision-Making methods (MCDM), AHP with ratings.

The use of this procedure enables the reduction of judgment numbers required to decision maker when the alternatives are numerous. Besides, it enables the insertion and removal of alternatives without inverting the ranking during the decision-making process.

The problem hierarchy in this paper considers "aspects" in the first level rather than criteria as we see in most applications. The reason for using "aspects" is a better perception and evaluation by the decision maker.

These characteristics are advantageous once they allow the representation of a complex problem of projects selection and prioritization. The application of the method was possible in this project because the problem had been structured before, with ratings defined by Lima and Damiani (2010).

However, there are many ways to evaluate and select projects for the problem. Thus, the parts involved must decide and adapt the best method to the problem decision, in agreement with its specific requirements.

For further studies, the implementation of procedures, ratings and BOCR (benefits, opportunities, cost and risks) in the AHP method is suggested.

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