Lizbeth Martínez Ramírez, Jaime Muñoz Flores, Arturo Torres Vargas

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The Analytical Hierarchy Process: An Optimal Methodology for Research in Entrepreneurship

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Lizbeth Martínez Ramírez*, **Jaime Muñoz Flores****, **Arturo Torres Vargas*****

The paper proposes the Analytical Hierarchy Process (AHP) as a mathematical tool for research into entrepreneurship through an example of its application, where the expected requirements of government policies to promote the creation of startups are identified. The study is structured on the AHP model in order to demonstrate quantitative and qualitative analytical foundations so as to determine alternatives that best fit the criteria to achieve multiple objectives. The results show the priority of government policies that best promote the creation of startups according to the directors of a set of Mexican University Business Incubators (UBIs). Research in entrepreneurship should be complemented with analytical tools that consider subjective judgments. The proposal of applying AHP models allows the obtaining refined assessments by selecting alternatives that meet the established criteria in order to reach an objective. This research provides evidence regarding the methodological advantage represented in the process of the hierarchy of alternatives based on mathematical analysis. The results of the applied scenarios exhibit AHP as a valuable resource in resolving problems that include relations between the qualitative and quantitative variables involved in the entrepreneurial framework.

Keywords: AHP, Entrepreneurship, Government policies.

Metoda Analytical Hierarchy Process – optymalna metodologia badań przedsiębiorczości

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W artykule zaproponowano metodę Analytical Hierarchy Process (AHP) jako narzędzie matematyczne służące do badania przedsiębiorczości. Podano przykład jej zastosowania, w którym wskazano wymogi, jakie powinna spełniać polityka państwa, aby wspierać tworzenie nowych przedsiębiorstw. Artykuł opiera się na modelu AHP w celu zaprezentowania ilościowych i jakościowych podstaw analitycznych pozwalających na określenie alternatyw najlepiej spełniających kryteria osiągania wielorakich celów. Wyniki wskazują na priorytetowe traktowanie polityki państwa, która według grupy meksykańskich akademickich inkubatorów przedsiębiorczości w najlepszy sposób wspiera tworzenie nowych przedsiębiorstw. Badania w dziedzinie

* **Lizbeth Martínez Ramírez** – Ph.D. student in Economic Sciences, Autonomous Metropolitan University; orcid.org/0000-0001-9182-4504.

** **Jaime Muñoz Flores** – Researcher, Professor, Ph.D. in Economic Sciences, Autonomous Metropolitan University.

*** **Arturo Torres Vargas** – Researcher, Professor, Ph.D. in Economics and Innovation, Autonomous Metropolitan University.

Correspondence address: Autonomous Metropolitan University, Economic Production, L–239; Calzada del Hueso 1100, Col. Villa Quietud, Delegación Coyoacán, C.P. 04960, D.F. México; e-mail: martinez7lizbeth@gmail.com.

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przedsiębiorczości należy uzupełnić narzędziami analitycznymi uwzględniającymi element subiektywności. Zastosowanie modeli AHP umożliwia dokonanie dokładniejszej oceny poprzez wybór alternatyw spełniających ustalone kryteria, aby osiągnąć zakładany cel. Przeprowadzone badania dowodzą metodologicznej wyższości zastosowania procesu hierarchicznej analizy alternatyw w oparciu o analizę matematyczną. Wyniki wykorzystanych scenariuszy ukazują AHP jako cenne narzędzie rozwiązywania problemów związanych z relacjami między zmiennymi jakościowymi i ilościowymi występującymi w ramach przedsiębiorczości.

Słowa kluczowe: AHP, przedsiębiorczość, polityka państwa.

JEL: L26, O38

1. Introduction

The complex environment of entrepreneurship and the small business framework has been fortified with qualitative and quantitative research that, most of the time, is identified in separated methodologies. Due to the importance of analyzing both types of data, this paper aims to propose the Analytical Hierarchy Process (AHP) as a mathematical tool for research into entrepreneurship through the example of its application, where the expected requirements of government policies promoting the creation of startups are identified.

The entrepreneurship environment involves a decision-making process that, most of the time, must accomplish multiple objectives simultaneously (Somsuk and Laosirihongthong, 2014). Furthermore, the alternatives to the solution that best fulfill the established criteria also tend to be multiple. It is therefore essential to formulate mathematical models with an analytical hierarchy for the wide variety of feasible qualitative and quantitative combinations among the objectives to be achieved through the established criteria and the best alternatives. This study is structured on an AHP model in order to look at quantitative and qualitative analytical foundations to determine, with mathematical formality, the alternatives that best fit the criteria to achieve multiple institutional or particular objectives.

The main contribution of this work is the proposal of the Analytical Hierarchy Process (AHP) as a tool for research into entrepreneurship. In order to validate such a proposal, we identify the criteria and alternatives that best promote the creation of startups on the basis of the main literature (Aernoudt, 2004; Carayannis and Von Zedtwitz, 2005; Autio, et al., 2014; Radosevic and Myrzakhmet, 2009). The developed model was applied to the directors of a set of Mexican University Business Incubators (UBIs). It allowed the identifying of their priorities through the AHP methodology (Saaty, 1977; Chang, 1996).

The paper is organized as follows: this introduction is considered as section one; section two presents the literature review and details of the AHP methodology (according to Chang, 1996) are developed; section three includes the AHP schemas for qualitative analysis as applied at UBIs that promote the creation of startups; finally, the discussion and conclusions are presented.

2. Literature Review

The qualitative and quantitative analysis of the entrepreneurship environment favors business decision-making, which has been recently characterized by the increase in the use of systems that consider available resources in order to get optimal schemes. This can be modeled using formal representations in order to clarify the relationships among needs, established objectives, and available resources. The actors involved in such an environment require performance parameters and indicators, hence certain fields of mathematics can play a fundamental role as auxiliary tools for the establishing of priorities among the diversity of required elements for an optimal decision-making process.

The application of analytical systems for decision-making is widely used by companies and consortia since it provides signals facilitating the anticipation of solutions to problems threatening their survival on the market. It can be said, in general, that most models include a combination of both normative and prospective aspects. Logical and symbolic representations among the elements of a decision-making system using semantic resources describe the qualitative and quantitative relations in a comprehensive way. Therefore, mathematical modeling, as a resource for understanding and communication, has received increasing attention within the management and business communities. In this work, AHP is considered an optimal tool enabling the relations mentioned above as described below.

2.1. The Analytical Hierarchical Process (AHP)

The Analytical Hierarchical Process (AHP) emerged at the beginning of the nineteen-eighties as a methodological resource that allows the combining of qualitative and quantitative information. To build a decision, the AHP model is based on the definition of multiple criteria as well as on the identification and weighting of alternatives that fulfill those criteria. Given its capacity to combine objectives, criteria, and multiple alternatives, the AHP theory is widely applicable for decision-making under conditions of uncertainty.

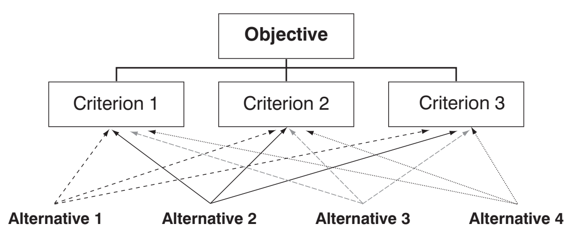

Fig. 1. Schematic Objective, Criteria, and Multiple Alternatives Representation. Source: own work.

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In the AHP model, subjective judgments based on the experience of the decision-maker are combined with available qualitative and quantitative information. As a result, this combination generates the determination of a consistent prioritization for the existing alternatives (Saaty, 1977).

As a methodological principle in AHP, the available information – qualitative and quantitative – is combined with value judgments based on the knowledge and expertise of the decision-maker. This combination allows the determining of the relevance of each criterion in relative terms.

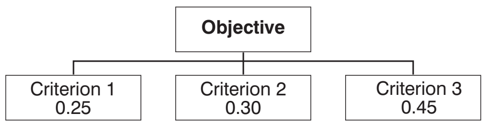

Fig. 2. Example of Relative Criteria Importance. Source: own work.

The AHP methodology involves pairwise comparisons between the existing alternatives, taking into account the degree of compliance that each alternative has with respect to each of the criteria. At this stage of the process, it is necessary to consider the series of transverse and longitudinal data that might exist as well as all available qualitative information that can be exploited for the establishment of value judgments.

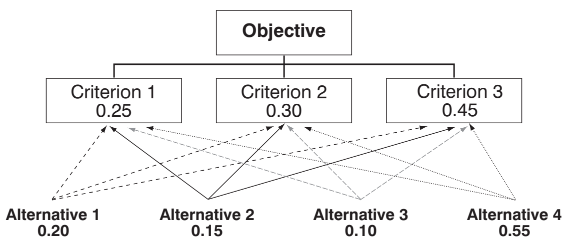

Fig. 3. Scheme of Multi-Criteria and Multi-Alternatives with Quantified Relevance. Source: own work.

As a result of this process, using the closed operations of matrix algebra, vector calculus corresponding to the ranking of alternatives takes place as a result of the integral combination of relevance relating to each one of the criteria.

	Criterion 1	Criterion 2	Criterion 3
Criterion 1	1	1	0.3
Criterion 2	1	1	1.0
Criterion 3	3	1	1.0

Tab. 1. Matrix of Criteria Pairwise Comparison. Source: own work.

Through matrix algebra, the AHP calculates the corresponding vector of the given alternatives with the integral combination of relative importance associated with each criterion, obtaining the global priority for the achievement of the objectives, whose notation is:

- For each given objective **i** = 1, 2, … **m**, where we solve the **Wi** weights
- For each objective **i**, we compare the **j** = 1, 2, … **n** alternatives and solve the $\mathbf{W_{ij}}$ weights with respect to objective **i**
- We solve the final $\mathbf{W_j}$ weight with respect to the objective, thus

$$\mathbf{W_j} = w_{1j}w_1 + w_{2j}w_2 + \ldots + w_{mj}w_m .$$

The weights of the alternatives are sorted in descending order according to **Wj** and the highest value indicates that this is the priority alternative to achieve the given objective and the one that best meets the criteria.

The AHP has received growing attention as a subject of research (both basic and applied), particularly in this century. This is largely due to the development of computer applications that allow the carrying out of operational processes of matrix algebra and vectors, permitting the simulation of scenarios and combinatory analysis as well as the application of numerically sophisticated methods for sensitivity analysis.

2.2. AHP Methodology

The theoretical principles underlying the AHP methodology were developed during the last decades of the 20th century. Basically, they are related to the fields of vector analysis and matrix algebra.

The AHP model conforms matrices on the basis of value judgments, in order to obtain quantitative values of the criteria and alternatives in the model. Evaluators select the level of importance of each criterion with respect to the others as well as the relative importance of the alternatives with reference to each criterion according to the Saaty scale (Saaty, 1977).

An example: Selection of the level of importance of the criterion “Eligible Budget” with respect to the criterion “Operational,” assuming that the evaluator gives a value of “5” to the criterion to the left with respect to its homologues (tab. 3).

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Intensity	Level of importance	Meaning
1	Equal	Two activities contribute in equal ways to the objective
3	Moderate	Experience and judgment slightly favor one activity over the other
5	Strong	Experience and judgment strongly favor one activity over the other
7	Very strong	One activity is greatly favored over the other
9	Extreme	Evidence of favoring one activity over the other is absolute and totally clear
2, 4, 6, 8	Intermediate values	Adjacent values
Reciprocal	$a_{ij} = 1/a_{ij}$	Hypothesis of the method

Tab. 2. The Saaty Scale. Source: own work based on Saaty (1977).

Comparison of criteria																		
Criterion ⬇ vs.	⟵								=								⟶	Criterion ⬇
Eligible budget	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operational

Tab. 3. Example of Comparison of Criteria. Source: own work.

The example shows that the criterion “Eligible Budget” is *strongly* more important than the criterion “Operational.” Each group of pairwise comparisons represents a support matrix of the final prioritization.

	Eligible budget	Operational	Resilient
Eligible budget	1	**5**	4
Operational	0.20	1	2
Resilient	0.25	0.50	1

Tab. 4. Matrix with Numerical Coefficients. Source: own work.

In order to represent the degree of importance held by a criterion of selection against others, the AHP methodology relies on the formation of a matrix of judgments. In Table 4, the numerical coefficients are registered and indicate which of the criteria is more important than the others.

In the above comparison process, whole numbers were used to indicate the importance of each criterion against others. The scales based on whole numbers determine strictly defined categories. However, the comparative judgments carried out by individuals are not usually strictly categorical. The presence of individual subjective perceptions makes necessary the consideration of a not strictly categorical metric of reference.

In Figure 4, a metric of strictly categorical reference is compared with another that is not categorical, which we call a fuzzy metric (Chang 1996). It can be seen that in the first case, each category is limited by a whole number.

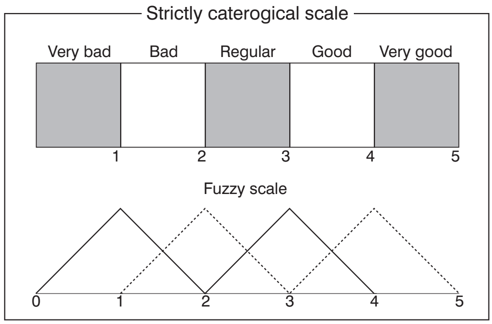


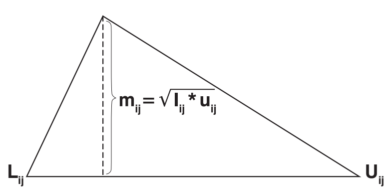
Fig. 4. Categorical Metric and Fuzzy Metric. Source: own work.

In contrast, there are overlaps in the fuzzy scale. This signifies that belonging to a category is not strict. This even allows the possibility of belonging to two categories simultaneously. Triangles that are formed by joining the vertices are known as real triangular fuzzy numbers and are represented as (0, 1, 2) or (3, 4, 5).

In general terms, Ã represents a matrix of judgments n*n that contains real numbers of the type triangular fuzzy numbers a_{ij} for all i, j $\in \{1, 2, \dots, n\}$ as shown in the following matrix.

$$\tilde{A} = \begin{pmatrix} (1,1,1) & a_{12} & \dots & a_{1n} \\ a21 & (1,1,1) & \dots & a_{2n} \\ \dots & \dots & (1,1,1) & \dots \\ a_{n1} & a_{n2} & \dots & (1,1,1) \end{pmatrix}$$

Where $a_{ij} = (l_{ij}, m_{ij}, u_{ij})$ with l_{ij} as the lower value, u_{ij} as the superior limit, and m_{ij} as the geometric average of l_{ij} and u_{ij}, which means:



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Assuming that M_1 y M_2 are two triangular fuzzy numbers with $M_1 = (l_1, m_1, u_1)$ y $M_2 = (l_2, m_2, u_2)$. The basic calculations are:

$$M_1 + M_2 = (l_1 + l_2,\ m_1 + m_2,\ u_1 + u_2)$$

$$M_1 \times M_2 = (l_1 l_2,\ m_1 m_2,\ u_1 u_2)$$

$$M_1 = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right).$$

According to Chang (1996), the following steps are required in order to determine the vector W of the hierarchy:

The vector of real fuzzy numbers is obtained by adding the rows of the matrix of fuzzy numbers A.

$$RS = \begin{bmatrix} rs_1 \\ rs_2 \\ \vdots \\ rs_n \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{n} a_j \\ \sum_{j=1}^{n} a_{2j} \\ \vdots \\ \sum_{j=1}^{n} a_{nj} \end{bmatrix} = \begin{bmatrix} \left(\sum_{j=1}^{n} l_j, \ \sum_{j=1}^{n} m_j, \ \sum_{j=1}^{n} u_j\right) \\ \left(\sum_{j=1}^{n} l2_j, \ \sum_{j=1}^{n} m_{2j}, \ \sum_{j=1}^{n} m_{j2},\right) \\ \vdots \\ \left(\sum_{j=1}^{n} l_{nj}, \ \sum_{j=1}^{n} m_{nj}, \ \sum_{j=1}^{n} m_{nj},\right) \end{bmatrix} \tag{1}$$

The row vector of fuzzy numbers (RS) is normalized in order to get a simplified vector S.

$$\tilde{s} = \begin{bmatrix} \tilde{s}_1 \\ \tilde{s}_2 \\ \vdots \\ \tilde{s}_n \end{bmatrix} = \begin{bmatrix} rs_1 \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \\ rs_2 \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \\ \vdots \\ rs_n \otimes \left(\sum_{j=1}^{n} rs_j\right)^{-1} \end{bmatrix} \tag{2}$$

Where $\left(\sum_{j=1}^{n} rs_j\right)^{-1}$ is derived from RS and is calculated by:

$$\left(\sum_{j=1}^{n} rs_j\right)^{-1} = \left(\frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}}\right),$$

Which is how the normalization of each component of the fuzzy triangular number should be done.

The possibilities for non-fuzzy values of the vector V have to be determined:

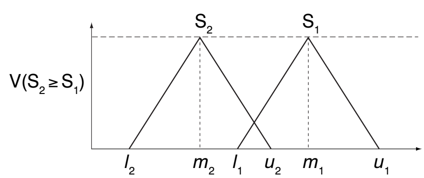
$$V = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ vn \end{bmatrix} = \begin{bmatrix} \min V(S_1 \geq S_k) \\ \min V(S_2 \geq S_k) \\ \vdots \\ \min V(S_n \geq S_k) \end{bmatrix} \tag{3}$$

Where: S_k is the normalized row vector from step (2).

The grade of possibilities of $S_2 = (l_2, m_2, u_2) \geq S_1 = (l_1, m_1, u_1)$ is obtained by:

$$V(S_1 \geq S_2) = \begin{cases} 1, \text{if } m_2 \geq m_1 \\ 0, \text{if } l_2 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 \geq l_1)} & \text{Other wise} \end{cases}$$

As is shown in the following figure:



Finally, the last normalization of non-fuzzy values of the W vector is determined:

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} v_1 / \sum_{i=1}^{n} v_i \\ v_2 / \sum_{i=1}^{n} v_i \\ \vdots \\ v_n / \sum_{i=1}^{n} v_i \end{bmatrix} \tag{4}$$

In which the final ranking of the alternatives is established.

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3. Schemas of AHP Application for Qualitative Analysis

As it has been discussed above, AHP models allow the solving of problems relating to decisions with objectives, criteria, and multiple alternatives. Computational algorithms allowing the application of Chang methodology for the simulation of decision scenarios and sensitivity analysis of the vector W for ranking alternatives were scheduled in order to carry out this research.

The aim of the research was the evaluation of expected requirements of government policies to promote the creation of new enterprises. The model was applied to the management level of the IPN, UNAM, and ITESM University Business Incubators (UBIs).[1] Three criteria were established as expected requirements regarding the mentioned governmental policy (Figure 5).

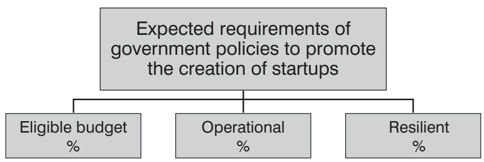

Fig. 5. Criteria to Be Met by the AHP Model. Source: own work.

The criteria for the model were selected on the basis of literature on BIs and entrepreneurship (Aernoudt, 2004; Aerts, Matthyssens, and Vandenbempt, 2007; Carayannis and Von Zedtwitz, 2005).

To be considered, any alternative leading towards the goal was required to comply with the "Eligible Budget," "Operational," and "Resilient" criteria[2].

With respect to the alternatives, among the variants developed in this research it was the one that fully represented the multiple graphs that was selected. This means a scheme of interrelated nodes with a represented node for each criterion. Such selection was based on Radosevic and Myrzakhmet (2009), Grimaldi and Grandi (2005), and Bergerk and Norrman (2008) and is outlined in Figure 6.

The process of pairwise comparison was carried out in order to apply a Chang version of the AHP model within the judgment matrix and fuzzy triangular valuations with $\Delta = 0$, followed subsequently by the corresponding normalizations for calculating the matrix products giving rise to the transposed vector W^t of the ranking of alternatives. Figures 7, 8, and 9 present the results.

The AHP model shown in Figures 5 and 6 was applied to experts in the promotion of entrepreneurship at the UBIs. The comparisons were performed in order to identify the expected requirements of public policies to promote the creation of new enterprises in such a way so that

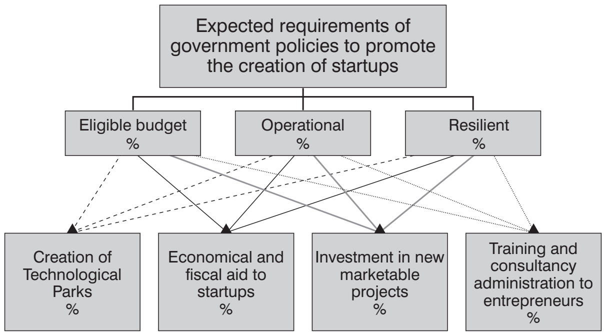

Fig. 6. Interrelated Nodes of Criteria and Alternatives. Source: own work.

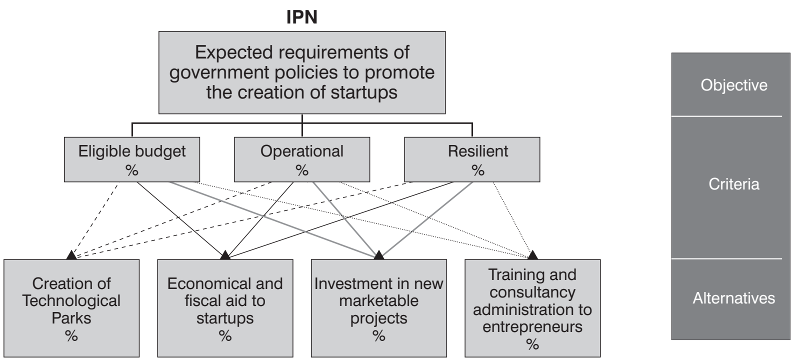

Fig. 7. IPN Multi-Criteria and Multi-Alternatives Quantified Relevance Scheme. Source: own work according to results obtained by the AHP model as applied to IPN.

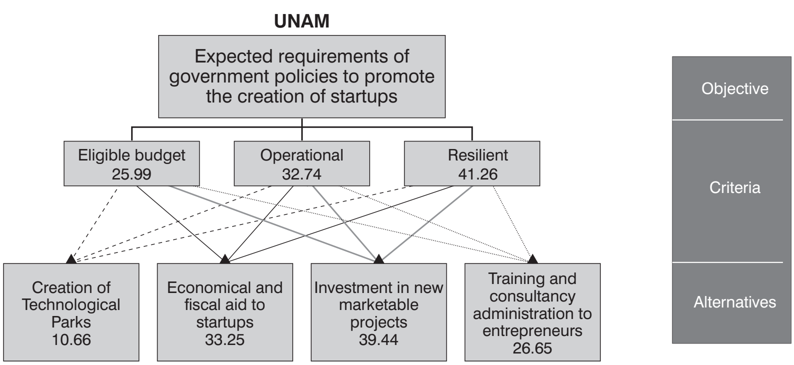

Fig. 8. UNAM Multi-Criteria and Multi-Alternatives Quantified Relevance Scheme. Source: own work according to results obtained by the AHP model as applied to UNAM.

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for each qualitative evaluator's judgments, four matrices were compiled and their transposed vectors W^t allowed to rank the alternatives. This way, the strategic importance for policies to promote the creation of enterprises was established in line with the following results (fig. 7).

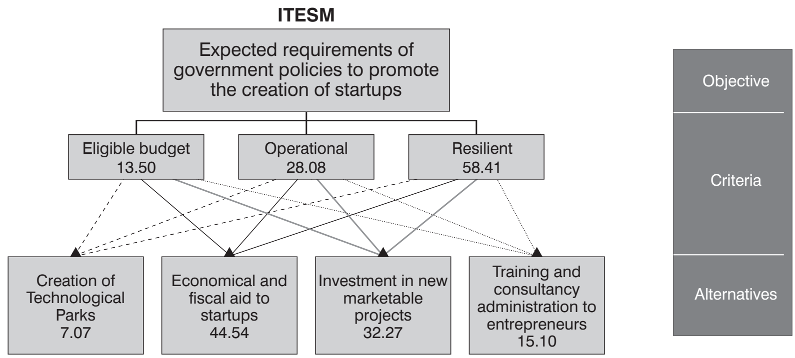

Fig. 9. ITESM Multi-Criteria and Multi-Alternatives Quantified Relevance Scheme. Source: own work according to results obtained by the AHP model as applied to UNAM.

Category	Criteria	IPN	UNAM	ITESM	Average	Alternatives	IPN	UNAM	ITESM	Average
Expected requirements of government policies to promote the creation of startups	Eligible budget	28.09	25.99	13.50	22.53	Creation of Technological Parks	21.07	10.66	7.07	12.93
	Operational	58.41	32.74	28.08	39.74	Economical and fiscal aid to startups	26.81	23.25	44.54	31.53
	Resilient	13.50	41.26	58.41	37.72	Investment in new marketable projects	28.65	39.44	33.27	33.79
						Training and consultancy administration to entrepreneurs	26.81	26.65	15.10	22.85

Tab. 5. Global Prioritization of Criteria and Alternatives of the Applied AHP Model. Source: own work according to results obtained by the AHP model as applied to IPN, UNAM, and ITESM.

To be able to make decisions once the prioritizations are ready, the most important alternatives are those whose weight value is higher. The applied model shows that the criterion called “Operational,” as pointed out by Aerts, Matthyssens, and Vandenbempt (2007) and Carayannis and Von Zedtwitz (2005), is most important and the priority alternative is the “investment in new marketable projects,” as pointed out by Grimaldi and Grandi (2005).

4. Discussion

Schumpeter’s research on entrepreneurship generated an interest that has prevailed for many decades. However, there is still something missing in that framework. As found by Aernoudt (2004) and Bergerk and Norrman (2008), among others important researchers, most studies have been quantitative or qualitative. According to Wong, Ho and Autio (2005), what is needed is the development of qualitative and quantitative evidence of entrepreneurship. In light of this fact, this work proposes the AHP as a tool for mixing both kinds of methods.

Using the example of the prioritization of alternatives to promote the creation of startups on the basis of an AHP model, it provides more certainty than other methods such as surveys, interviews, or descriptive works, because the subjective judgments of the evaluators can be represented in such a model. What was found was that the AHP method provides a refined and useful perspective for research on entrepreneurship. This work is an example of the application of a qualitative and quantitative method that allows prioritization according to certain established criteria. The results of the assessment show that “investment in new marketable projects” (Grimaldi and Grandi, 2005) are the priority of the directors of the studied UBIs, where the most important criterion for them is “Operational,” which means that UBIs request that specialized people develop activities fostering the creation of startups (Aerts, Matthyssens, and Vandenbempt, 2007; Carayannis and Von Zedtwitz, 2005).

In this work, the criteria and alternatives of government policies to promote the creation of startups that the three most important Mexican UBIs prioritize have been identified on the basis of literature. Nevertheless, it is fundamental to extent the analysis to other UBIs in different regions, especially in developing countries (Radas and Bozié, 2009).

The proposal contained in this work is intended to complement the entrepreneurship framework with analytical tools that provide certainty as to subjective judgments and allow the combining of qualitative and quantitative methods. The proposal to apply AHP models allows the obtaining of refining assessments by selecting alternatives that meet the established criteria in order to reach an objective as developed by Saaty (1977) and Chang (1996).

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5. Conclusions

The applied model of AHP allows the identification of the expected requirements of government policies to promote the creation of startups. According to the directors of the evaluated Mexican UBIs, investment in new marketable projects is the most important strategy to achieve the objective of creating new enterprises.

The qualitative analysis is an eminently complex path that usually brings significant results to the decision making process involved in entrepreneurship. For this reason, the construction of scenarios by combining objectives, criteria, and alternatives is fundamental to the planning and development of strategic programs directed at enterprise consolidation.

This research provides evidence regarding the methodological advantage representing the process of the hierarchizing of alternatives based on mathematical analysis. The results of the presented scenarios demonstrate AHP as a valuable resource for resolving scenarios that include the multiplicity and complexity of the relations between the qualitative and quantitative variables involved in the entrepreneurial framework. Although this work focused on a selection of Mexican UBIs, the AHP, the developed methodology can be easily applied to contribute to the articulation of policies and strategies of entrepreneurship´s promotion in any region of the world.

Endnotes

1 IPN, UNAM, and ITESM are the Spanish abbreviation for the National Polytechnic Institute, the Autonomous National University of Mexico, and the Technological Institute of Higher Studies of Monterrey, respectively.

2 The criterion "Eligible Budget" refers to the availability of financial resources. The criterion "Operational" is related to the availability of the optimal human resources to develop the required activities. The criterion "Resilient" refers to the low vulnerability of the environment.

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