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RESEARCH ARTICLE

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INTEGRATED PURCHASE MANAGEMENT: A PROCESS MODEL FOR SUPPLIER SELECTION BASED ON FUZZY LOGIC

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ABSTRACT

The search for competitive advantage through the interconnection of organizational processes allows the reduction of time and expenses for companies. Therefore, this study had as main objective to propose strategies that allow to find good practices for these actions, whose main objective was to present a model for the selection process of suppliers based on fuzzy logic to improve activities. In this context, integrated purchasing management, supplier selection, fuzzy logic, its pertinence variables and the use of rules established to meet the procurement procedures of a foundation to support Research, Extension and R&D. Finally, the result is a final assessment of suppliers, using the fuzzy inference method developed in the Matlab® software, in the Fuzzy Logic Toolbox environment, in the Mamdani model, taking into account the social and economic criteria for a possible purchase of a very relevant electronic product in the institution, allowing this tool to become practical and applicable to the needs of the sector. After data obtained, it was concluded that the model proved to be very efficient, presenting a minimum difference from one supplier to the other, where the first place obtained a score of 2.06 more in relation to the selected room, seen as the longest distance in compared to the other classifieds, and it is important to continue the relationship with them in future acquisitions, one must also adopt the use of tools to recover those that did not show good results, in addition to the development of new suppliers. taking into account the social and economic criteria for a possible purchase of a very relevant electronic product in the institution, allowing this tool to become practical and applicable to the needs of the sector.

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INTRODUÇÃO

In the modern corporate world, much is said about the integration of sectors as an evolutionary way for business success, but to accompany this progress, the institution's interaction with business factors is inherent, requiring greater control of the organization. For the permanence of companies, the creation of strategies has been an important element, as new practices appear that modify the market mechanisms requiring a greater effort to adapt to these changes and stay ahead of its competitors. For this reason, companies have been looking for guarantees in their businesses to generate profits and decrease expenses. Thus, it is essential to find alternatives that contribute to this, as integrated management has been gaining great visibility in the administrative process every day, especially in large industries, for allowing the manager to see the organization as a whole. The distribution of an institution's operations through a system is considered integrated management, as it promotes communication, confirming that the guidelines are followed to achieve goals and solve problems at all levels and sectors (MOREIRA and LOPES, 2016).For SOUZA *et al*. (2018), this integration has been fundamental in the supply area, since purchasing management is essential for companies from production to deliveries to the final consumer, being extremely important that it is integrated through a system to define a series of strategies, enabling the acquisition of supplies and supplies necessary for the maintenance and functioning of the organization. With the modern management of the purchasing area, the supplier selection process has been considered a strategic activity, as it requires an extensive evaluation of many criteria, not only depending on one main, but also on other significant aspects, such as environmental factors, social and economic issues, important for companies (BAI and SARKIS, 2010).According to ANDRADE *et al*. (2019), supplier selection is a process to find companies able to supply goods and services through various criteria, causing a direct impact on the company's performance. According to SILVA *et al*. (2016), in the decision-making process, the criteria for selecting suppliers are considered key elements, as it assists the policyholder in systematically evaluating a set of alternatives in relation to various methods. For this reason, organizations have developed selection tools that address the main criteria, in a way that is understandable to policyholders, with transparency for suppliers (LIMA JUNIOR *et al*., 2013a). According to MAGALHÃES (2014), information management has premises for decision making in companies, making it possible for the procurement administration to develop procedures based on fuzzy logic that can evaluate criteria considered to be very consistent in the purpose of helping managers in the management process and choosing suppliers. CINTRA (2012), states that fuzzy theory is a form of multivalued logic, being a proposition that always assigns the truth-values, true (1) or false (0) and can be used as a support system in decision making , because it proposes to work with the imprecision of human thought, identifying results that provide an improvement in the choice of several criteria (CHERRI *et al*., 2011). In this context, it is important to understand the conditions of integrated purchasing management, as it is the activity responsible for carrying out negotiations with a focus on cost reduction, but maintaining the quality of the materials purchased. In view of the above, the present study aims to present a model of supplier selection process based on fuzzy logic for decision-making in purchasing management.Therefore, this work is justified based on the premises extracted from the literary universe and from private information on the methods of purchasing management in the supplier selection process, which can be applied in any institution, the results of which allow a more systematic view of the form this type of management that has been developed in industries and other organizations, providing the use of improvement techniques in their activities.

LITERATURE REVISION

Currently, the business sectors in an organization are integrated with each other, facilitating its administration and sharing common interests. SOUZA and DIAS (2015), affirm that this way of conducting institutional activities has caused purchasing management to change in the last decades, ceasing to be considered an operational activity, becoming seen as a fundamental part in the company's growth process developing information system strategies for carrying out acquisitions and contracts, supporting decision making and adopting performance indicators to reduce costs, aiming at optimizing results (AMATO NETO, 2014).DIAS and COSTA (2012), report that for a good performance of an organization it is necessary to carry out the correct management of the purchasing process, which can be through a system that defines a series of strategies and enables the acquisition of important supplies and inputs for the functioning of the company. The purpose of the purchasing management integration process is the search for competitive advantage, and the connection of the links is of paramount importance, as it is part of the chain structure and its interconnections, allowing for a reduction of time and expenses, in addition to a good relationship with suppliers to guarantee quality and lower cost (SOUSA and ALMEIDA, 2015). BALLOU (2006), says that due to the accelerated technological advance, purchasing management has been creating several opportunities for organizations, through innovation,

Purchasing sector: According to SOUZA and DIAS (2015), purchasing is the sector that presents great complexity, as it involves a set of factors and techniques that directly influence the company's results, so it is important to provide well-designed strategies, such as market analysis, allowing a better perception of the bargaining power in negotiations to generate profits (MONTEIRO and TINOCO, 2015). According to NACK and BONFADINI (2013), the purchasing sector has an important role in the organization and, over time, has shown a visible evolution in its functions.This activity is responsible for supplying the company with goods and services safely, within the specified standard, carrying out negotiations with suppliers, with the mission of whenever possible to reduce costs and maintain the quality of the purchased materials, with a view to guaranteeing the functioning and performance best of their production (SOUZA and DIAS, 2015). Purchasing activities are being increasingly valued by organizations, as they are focused on competitiveness strategies that directly interfere in their productive and financial areas, considered allies because they contribute to the institution's gain. One of the relevant factors for this growth is the selection of suppliers, which is why it has been gaining importance in the sector, due to the analysis of several criteria when purchasing a material or contracting a service (TEIXEIRA and BARBOSA, 2015). According to SOUZA and DIAS (2015), the purchasing activity when well structured, can generate strategic advantage for the company. Table 1 shows some considerations about the sector.

Table 1 - Considerations on the purchasing sector

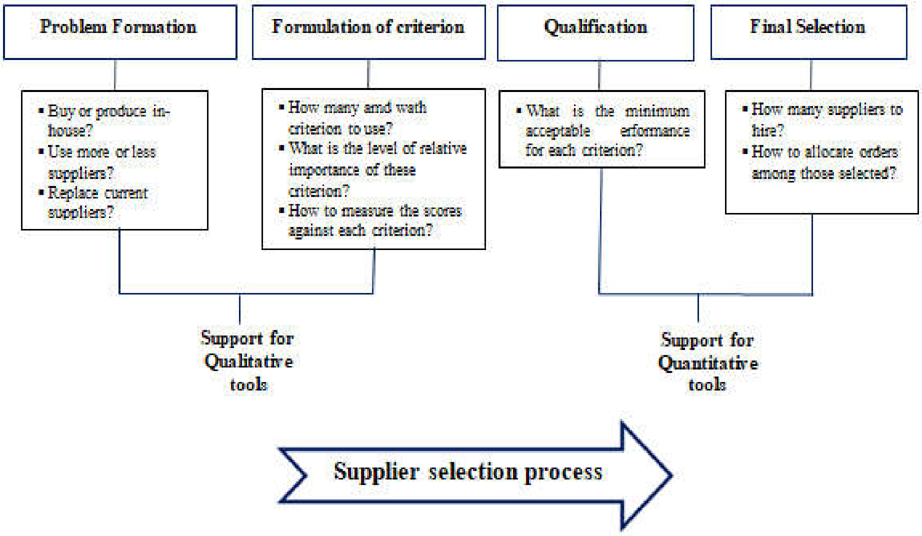
Purchases	It is the acquisition of a good or a right for which a stipulated price is paid.
The act of buying	It is a set of actions that organizations must take to purchase all the products and services necessary for their production and / or operation.
The purchasing sector	It is the department in charge of the act of buying. Responsible for choosing suppliers, negotiating prices and purchasing conditions, establishing purchase orders and contracts, executing all procedures for receiving purchased goods and services, and paying for purchased products, when these are not delegated to the company's financial sector.

Source: Adapted from SOUZA and DIAS (2015).

Supplier selection process: Supplier selection is an activity of the most relevant purchasing management, as it leads to decision-making situations, where the results directly influence the costs of the organization (LIMA JUNIOR and CARPINETTI, 2015). This process arises from the managerial decision when contracting the supply of products or services necessary for the operation of the company (VIANA and ALENCAR, 2012). The periodic evaluation of the suppliers' performance is very important for the organization to be able to verify if they are meeting the contractual obligations and identify those with underperforming performance (CARVALHO *et al*., 2014). The first step in the process usually involves recognizing the duty to evaluate and select a supplier for a good or service and needs to start before the need to purchase,For LIMA JUNIOR and CARPINETTI (2015), the selection of suppliers is complex and important, requiring a transparent approach through the use of methods that support multicriteria at the moment of decision, such as models based on mathematical programming, statistics and artificial intelligence.According to SILVA *et al*. (2016),these methods emerged to facilitate and make the choice process more efficient, with the objective of encompassing criteria at the time of decision, such as the fuzzy approach, which is indicated especially in modeling considered complex and involves both qualitative and quantitative variables, where they simulate elements of the human thought, its decision-making process is based on linguistic variables, and may present vague and inconsistent information (GALO *et al*., 2016).LIMA JUNIOR and CARPINETTI (2015), state that for the development of the application of criteria and methods for the choice of suppliers it is necessary to be based on the particularities of the company and the supply strategy, it is not easy to convert its needs, which are often expressed as qualitative concepts in useful criteria, which must be specific requirements, which can be assessed quantitatively (ANDRADE *et al*., 2019). According to VIANA and ALENCAR (2012), the complexity of the supplier selection process is greater when aspects related to the peculiarities of the products are considered, and the appropriate set of methods must present the characteristics of each operation, including or excluding criteria without causing uncertainty. in the results (LIMA JUNIOR *et al*., 2016).

Supplier selection criteria: The evaluation of the criteria for the supplier selection process can be considered a complicated task due to its nature and quantity of product to be purchased or contracted service. The qualitative factors for the choice end up making it difficult to estimate because of the high subjective character, mainly because it is common to have conflicting aspects, such as quality and price that need to be balanced.(VIANA and ALENCAR, 2012).For LIMA JUNIOR and CARPINETTI (2015), the criteria to be used in the selection of suppliers must be precise and coincide with the objectives and goals of the company, in addition to having specific names, they must also be comparable and universal, in view of various operating conditions. According to PARK*et al*. (2010), the supplier selection process can be structured in 4 main stages considered interrelated, as shown in Figure 1 and Table 2.

Support methods for the selection of suppliers: For WU and BARNES (2011), several academic research indicates the use of several quantitative methods capable of assisting managers in complex situations and uncertainties in the qualification and final choice of suppliers, therefore, the more structured the definition stage is, the more it will provide techniques and models to support decision making of decision (PACHECO and GOLDMAN, 2019).According to LIMA JUNIOR and CARPINETTI (2015), a requirement of choosing the technique used for the development of suppliers is to deal with the dynamics of the performance system, since the interest in evaluating the use of these methods considered criteria, are important in the relationship between customers and their suppliers (GUARNIERI, 2015).



Source: Adapted from LIMA JUNIOR and CARPINETTI (2015).

Figure 1. Supplier selection process

Table 2. Criteria for selecting suppliers

Criteria	Proposed by
Technical Capacity, Commitment to quality, Cost / Price, Delivery, Communication, Compliance, Geographic Location, Financial Power, Relationship and Response to change.	KANNAN and TAN (2002).
Technical Capacity, Commitment to quality, Reliability of delivery, Cost / Price, Communication, Flexibility, Guarantee, Reputation and Response to change.	KATSIKEAS *et al*. (2004).
Technical Capacity, Commitment to quality, Delivery, Communication, Compliance, Geographic Location, Financial Power, Reputation and Response to change.	CHAN and KUMAR (2007).
Technical Capacity, Delivery Reliability, Cost / Price, Delivery, Communication, Compliance, Financial Power, Reputation and Response to change.	KIRYTOPOULOS *et al*. (2008).
Commitment to quality, Reliability of delivery, Relationship and Reputation.	GUNERI *et al*. (2009).
Technical Capacity, Warranty and Compliance.	SHEN and YU (2009).
Delivery reliability, Cost / Price, Product performance, Delivery, Communication, Environmental factors, Guarantee, Relationship and Response to change.	ORDOOBADI (2009).
Cost / Price, Delivery, Compliance and Relationship.	Boran et al. (2009).
Technical Capacity, Delivery Reliability, Product Performance, Financial Power, Relationship and Reputation.	AMIN and RAZMI (2009).
Technical Capacity, Commitment to quality, Cost / Price, Delivery, Compliance, Geographic Location, Financial Power and Response to change.	KU *et al*. (2010).
Technical Capacity, Cost / Price, Product Performance, Delivery, Communication, Warranty, Compliance, Geographic Location, Relationship and Reputation.	WANG (2010).
Technical Capacity, Commitment to Quality, Cost / Price, Product Performance, Delivery, Communication, Warranty, Compliance, Geographic Location, Relationship and Reputation.	LIN *et al*. (2011).
Technical Capacity, Commitment to Quality, Cost / Price, Product Performance, Environmental Factors, Social Factors, Compliance and Financial Power.	BÜYÜKÖZKAN and ÇIFÇI (2011).
Technical Capacity, Commitment to quality, Cost / Price, Delivery, Environmental factors, Flexibility, Compliance, Geographic Location and Financial Power.	AMINDOUST et al. (2012).
Commitment to quality, Cost / Price, Delivery, Flexibility, Compliance and Financial Power.	PRAJOGO et al. (2012).
Technical Capacity, Commitment to quality, Cost / Price, Communication, Environmental factors, Flexibility and Compliance.	GARCÍA et al. (2013).

Source: Adapted from LIMA JUNIOR and CARPINETTI (2015).

Second ANDRADE *et al*. (2019), it is possible to identify some techniques to support the selection of suppliers that can assist decision makers, these models are classified as:

- **Mathematical methods:** able to consider imprecision, risks and subjectivity, so they perform better in situations of certainty;
- **Statistical methods:** they can determine probabilities of the occurrence of some events, they are directed to situations of random uncertainties;
- **Artificial intelligence products:** able to deal with uncertainty phenomena, in this way, present better performance (ANDRADE *et al*., 2019).

The most used mathematical programming methods in organizations are: AHP (Analytic Hierarchy Process), ANP (Analytic Network Process), DEA (Data Envelopment Analysis), among others. In the approaches based on statistics and artificial intelligence, the following stand out: Fuzzy Set Theory (FST), Case-Based Reasoning (CBR), Gray Set Theory (GST), Genetic algorithm (GA) and others (ANDRADE *et al*., 2019).The use of these models considered multicriteria (for being a set of methods), is very important in companies to support right choices, even if countless criteria influence, because it does not aim at a single truth by a selected action, but at supporting the process in a way that the satisfactory decision as a solution, is in accordance with the rules defined by the borrowers (LONGARAY *et al*., 2017). The multicriteria methods propose methodologies that support the selection of suppliers in the management of purchases, but that can be used in several cases, in decision making in several organizational areas, their modeling can be of simple and combined approaches (LIMA JUNIOR and CARPINETTI, 2015).In Table 3 and 4 these techniques of simple approach and the techniques considered combined approach are presented.

As it was possible to observe in Tables 3 and 4, these methods can be of simple approaches (with techniques that help managers in situations of complexity and uncertainty) or, combined (where two or more techniques are used to support decision making), capable to deal with the peculiarities of different situations in the supplier selection process (LIMA JUNIOR *et al*., 2013a). In FFigure 2 shows some methods of simple and combined approaches that stand out the most in organizations in supporting decision making in the supplier selection process.

Fuzzy Logic: Fuzzy logic is considered an extension of Boolean logic, which admits only the values "false" [0.0] or "true" [1.0], in the case of fuzzy theory, the interval is allowed [0.0] and [1.0], who propose to work with the imprecision of intermediate levels between these values, being widely used by decision makers in statistical concepts in the generation of inference in the qualitative criteria evaluation process (BARACHO and MAGALHÃES, 2013). Developed by Zadeh in 1965, after publishing the article Fuzzy Sets, where he rediscovered the idea of fuzzification, fuzzy logic is widely used in the decision-making area, as it aims toAccording to CHEGOSKI *et al*. (2017), fuzzy logic was first introduced in 1930 by the Polish philosopher and logician Jan Lukasiewicz, by studying terms such as high and low, old and hot, proposed the use of a range of values [0.1], indicating a possibility of being true or false. In 1937, the philosopher Max Black defined the first fuzzy set describing some basic ideas of operations (RIGNEL *et al*., 2011). According to TEIXEIRA and BARBOSA (2015), the fuzzy approach is one of the methods widely used to solve this type of problem of supplier evaluation criteria, as it is considered a necessary structured tool in the decision process for dealing with subjectivity. The classification values by criterion through linguistic variables of the fuzzy logic fits the needs of a tool that defines classification degrees as "excellent quality" or "total commitment" that allows the mapping of values in an understandable way, capturing your intuition, while at the same

Table 3. Multicriteria methods - Simple approach

Simple Approach		
Technique (s) used	Scope	Proposed by
AHP	Selection of suppliers using paired comparative assessments / Selection of suppliers in a telecommunications company / Selection of suppliers with a focus on collaborative reduction of CO2 emissions.	HUDYMÁCOVÁ et al. (2010) / TAM and TUMMALA (2001) / THEIßEN and SPINLER (2014).
Genetic Algorithm	Selection of suppliers and dimensioning the size of acquisition lots / Selection of suppliers with compensatory and non-compensatory rules.	LIAO and RITTSCHER (2007).
Fuzzy inference	Supplier selection based on social, economic and environmental aspects.	AMINDOUST et al. (2012) / LIMA JUNIOR et al. (2013b).
TOPSIS	Selection of information technology service providers / Selection of suppliers in a manufacturing industry.	HSU and HSU (2008) / VIMAL et al. (2012).

Source: Adapted from LIMA JUNIOR and CARPINETTI (2015).

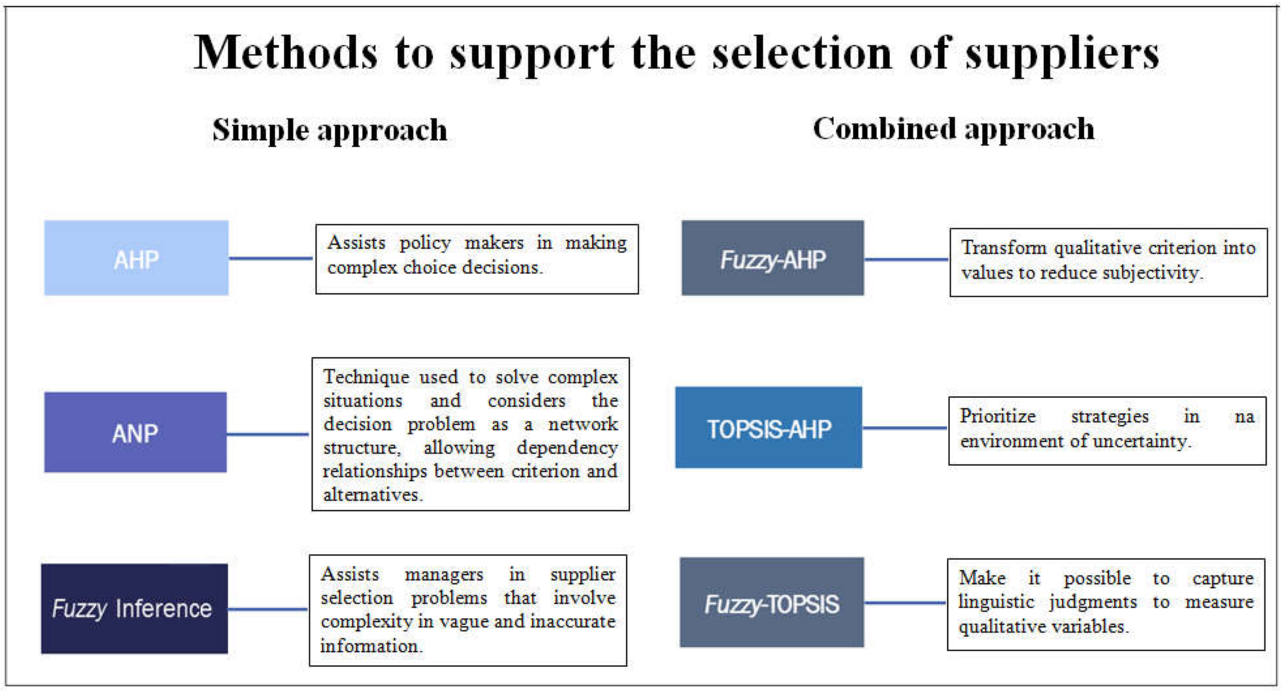
Table 4. Multicriteria methods - Combined approach

	Combined Approach	
Technique (s) used	Scope	Proposed by
DEA and Artificial Neural Networks	Selection and evaluation of suppliers in scenarios with incomplete information.	ÇELEBI and BAYRAKTAR (2008).
Fuzzy 2-Tuple	Vendor selection using a hierarchical linguistic computing approach.	WANG (2010).
Fuzzy-AHP	Selection of suppliers in a washing machine company.	KILINCCI and ONAL (2011).
Fuzzy c-means and rough set theory	Selection, evaluation and development of suppliers.	OMURCA (2013).
Fuzzy-DEMATEL and Fuzzy-TOPSIS	Selection and evaluation of "green" suppliers.	BÜYÜKÖZKAN and ÇIFCI (2012).
Fuzzy Neural Network	Selection and evaluation of suppliers in scenarios with incomplete information in just-in-time production environments.	AKSOY and ÖZTÜRK (2011).
Fuzzy-QFD	Selection of suppliers considering the dependency relationships between the criteria.	DURSUN and KARSAK (2013).
Fuzzy-TOPSIS	Selection of suppliers using trapezoidal fuzzy numbers / Selection of logistics service providers / Selection of suppliers using a hierarchy of criteria and subcriteria / Selection of suppliers based on the environmental performance of suppliers / Selection of suppliers considering tangible factors.	CHEN et al. (2006) / BOTTANI and RIZZI (2006) / SHAHANAGHI and YAZDIAN (2009) / AWASTHI et al. (2010) / LIAO and KAO (2011).
Fuzzy-TOPSIS and Fuzzy –ANP	Selection of long-term suppliers in a telecommunications company.	ÖNÜT et al. (2009).
Fuzzy multiobjective programming	Selection of suppliers considering the restrictions of decision makers.	ARIKAN (2013).
TOPSIS and ANP	Selection of suppliers in an electronic industry.	LIN et al. (2011).

Source: Adapted from LIMA JUNIOR and CARPINETTI (2015).

time that it is not distanced from the formalization of the problem (CARVALHO *et al*., 2014). For FERNEDA and DIAS (2013), they emphasize that the Fuzzy logic aims to capture and operate the uncertainty and partial truths of nature's phenomena with diversity in a rigorous and systematic way. Because this theory has the aspect of dealing with vague information, combining concepts of classical logic and sets with degrees of pertinence (CHEGOSKI *et al*., 2017).

Membership functions: RIGNEL *et al*. (2011), state that depending on the context inserted, the membership functions are of different forms, as can be considered the linguistic variable “size”, consisting of the following terms: T (size) = {low, medium, high}, which it can correspond to fuzzy sets b, mea, defined by their pertinence functions, as shown in Figure 3.This use of linguistic variables is very important for decision making in modeling the problem, as it



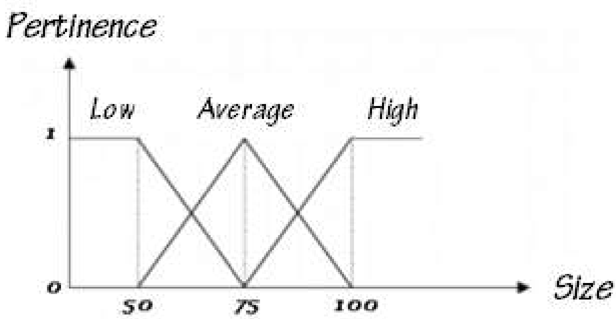
Source: Adapted from LIMA JUNIOR *et al.* (2013a).

Figure 2. Methods to support the selection of suppliers

Table 5. Linguistic terms and values

Linguistic Terms	Linguistic Values
Low	(1.0 3.0 5.0)
Average	(3.0 5.0 7.0)
High	(5.0 7.0 9.0)

Source: Adapted from UYGUN and DEDE (2016).



Source: Adapted from RIGNEL et al. (2011).

Figure 3. Membership functions for variable

Linguistic variables: The names of fuzzy sets, considered “values” are linguistic variables, whose main function is to provide an approximation of complex phenomena in a systematic way, such as “size”, which can be defined as a linguistic variable and its values (terms) they can be represented as low, medium and high (RIGNEL *et al*., 2011). For UYGUN and DEDE (2016), a variable is used to express the imprecise (linguistic) way of a problem, which can be used for decision making, as the evaluation criteria often cover several complex factors, as shown in Table 5.According to RIGNEL *et al*. (2011), the values of a linguistic variable can be sentences for a specific language, created from proper terms (low, medium, high).

manifests the imprecise way of human judgment, transforming it into quantitative variables (UYGUN and DEDE, 2016).

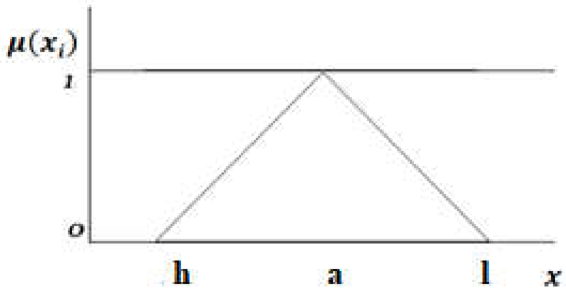
Fuzzy set: According to ROSTAMZADEH *et al*. (2015), the elaboration of the fuzzy set theory was based on the assumption that not only the main element of human judgment is summarized in numbers, but also in labels and linguistic terms, as a partial truth concept is expressed by diffuse logic, being able to determine values between the limit totally true (1) and totally false (0) (BARACHO and MAGALHÃES, 2013). According to BARACHO and MAGALHÃES (2013), age as a linguistic variable with the terms (young, average, old), can be considered as a fuzzy set, making it possible to state that a 22-year-old individual is young and at the same time has an average age.According to GALO *et al*. (2016), a set A in X characterized by a μA (x) membership function associated with each point x in X at a real value in the interval [0.1] representing the degree of inclusion of x in AA (X) is a bivalent function, as it results in only one or zero, will depend on whether element x belongs to set A (LIMA JUNIOR *et al*., 2013a). The bivalent function can be described by Eq. (1).

$$\mu_A(x) = \begin{cases} 1 \text{ se } x \in A \\ 0 \text{ se } x \in A \end{cases} \quad (1)$$

You can also correspond by triangular fuzzy numbers (GALO *et al*., 2016). In the pertinence function, these variables represent all ∈ X, obtained by Eq. (2).

$$\mu(x_i) = \begin{cases} 0, & if\ x_i \leq a \\ \frac{x_i - a}{m - a}, & if\ x_i \in [a, m] \\ \frac{b - x_i}{b - n}, & if\ x_i \in [n, b] \\ 0, & if\ x_i \geq b \end{cases} \quad (2)$$

The triangular fuzzy number of the function shown in Eq. (2) can be seen in Figure 4.



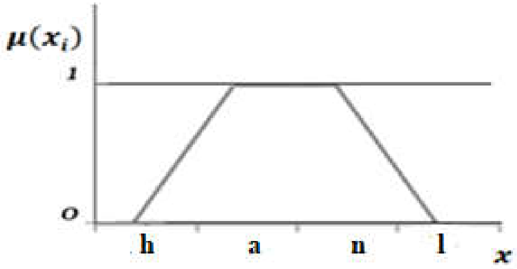
Source: GALO *et al*. (2016).

Figure 4. Triangular fuzzy number

Trapezoidal membership functions are the variables represented by trapezoidal fuzzy numbers (GALO *et al*., 2016). The membershipfunction that represents allx_i ∈X can be seen in Eq. (3).

$$\mu(x_i) = \begin{cases} 0, & if\ x_i \leq a \\ \frac{x_i - a}{m - a}, & if\ x_i \in [a, m] \\ 1, & if\ x_i \in [m, n] \\ \frac{b - x_i}{b - n}, & if\ x_i \in [n, b] \\ 0, & if\ x_i \geq b \end{cases} \quad (3)$$

Figure 2.5 represents the trapezoidal fuzzy number of the function shown in Eq. (3).



Source: GALO *et al*. (2016).

Figure 5. Trapezoidal fuzzy number

For GALO *et al*. (2016), a fuzzy set is normal, if and only if, there is at least one element with μA (x) = 1. It can also be convex, if and only if, ∀*x1* and x2 ∈ X and ∀*λ*∈ [0,1],*fA(x)*[*λx1+(1-λ)x2*]≥*min*[*fA(x1), fA(x2)*] and, obtain through the operations: : *A*∩*B=min*(*μA(x),μB(x)), ∀x∈X* and *A*U*B=max*(*μA(x),μB(x)), ∀x∈X*, the intersection and the union between two fuzzy sets *A* and *B* (LIMA JUNIOR *et al*., 2013a).

According to LIMA JUNIOR *et al*. (2013a), the algebraic operations with fuzzy numbers of the sets, either A = *A=(a1,b1,c1)* and *B=(a2,b2,c2)*, for a1≥0, b1≥0, c1≥0 e a2≥0, b2≥0, c2≥0, addition, subtraction, multiplication and division can be seen in Eq. (4) to Eq. (7).

$$A + B = (a1 + a2, b1 + b2, c1 + c2) \quad (4)$$

$$A \times B = (a1 \times a2, b1 \times b2, c1 \times c2) \quad (5)$$

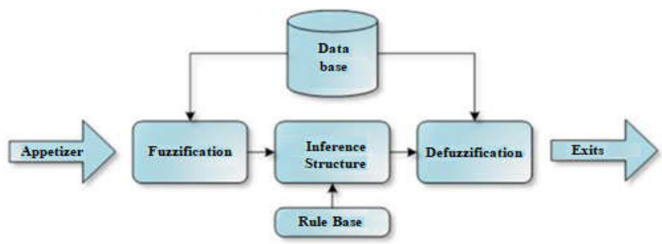
$$A - B = (a1 - a2, b1 - b2, c1 - c2) \quad (6)$$

$$A \div B = (a1 \div a2, b1 \div b2, c1 \div c2) \quad (7)$$

GALO *et al*. (2016), also report that the theory of fuzzy sets can offer a natural path between a set and its subsets for mapping relationships.AFFUL-DADZIE *et al*. (2016), state that in order to create a base of rules for the theory of fuzzy sets, mathematical rules are used, requiring coherent reasoning to meet what is intended to be achieved. Sogeneral a linguistic rule is:

IFpremise **THEN** consequence.

Fuzzy system: Fuzzy systems are being increasingly incorporated into business, due to their ability to handle qualitative information, their input is converted into a variable, followed by the inference structure that assesses the base of rules that are defined (GALO *et al*., 2016). Thus, the fuzzy system is based on rules and composed of a set, its inference technique makes use of fuzzy logic to perform the calculations, with two reasoning methods: the direct method and the fuzzy modeling method (FRANCE, 2015).According to LIMA JUNIOR *et al*. (2016), the first time that the fuzzy inference system was proposed, was in 1975, by Mamdani and Assilian, called the direct method, used in the decision process, undergoing some modifications since its original version. In 1983, Takagi and Sugeno proposed the simplified fuzzy modeling method for decision making (FRANCE, 2015). According to CHEGOSKI *et al*. (2017), in the fuzzy inference these two models are the ones that stand out the most in supporting decision making.The Mamdani method transforms the input variables into fuzzy sets generated at the output, in proportional numerical quantities. In the case of the Takagi-Sugeno method, it processes the input fuzzy data together with the rules for inferring contributions at the output (ANDRADE and JACQUES, 2008).In Figure 6, it is possible to observe the structure of the fuzzy inference system, consisting of five main elements: fuzzification interface, rules base, database, inference structure and defuzzification interface (LIMA JUNIOR *et al*., 2016).



Source: GALO *et al*. (2016).

Figure 6. Fuzzy inference system

Fuzzification:in this stage, linguistic variables aredefined subjectively, in addition to the pertinence functions. The analysis of the problem is encompassed, as well as the definitions of the variables, pertinence functions and creation of regions. Several types of space can be generated for each variable in the definitions of the pertinence functions, such as triangular, trapezoidal, Gaussian and generalized bell (CHEGOSKI *et al*., 2017).

Rules base: use of operators of inference methods and have a structure generally formed of two main parts: IF <previous> THEN <consequential> (from English if-then) that describe the specifics of the problem (GALO *et al*., 2016).

Data base: the number of input variables is defined by the information base, their types, values for linguistic terms, fuzzy operators, with the mapping of linguistic variables in fuzzy sets (GALO *et al*., 2016).

Inference: stage in which the rules are defined and embedded in a parallel way, where the definition of the propositions, analysis of the rules and creation of the resulting region are included. The key tool of fuzzy logic is the proposal of the relationship between logic variables and fuzzy regions (CHEGOSKI *et al*., 2017).

Defuzzification: the fuzzy values are converted in this step into real numbers having a mathematically defined output set, and corresponds to the functional link between the nebulous regions and the expected value (GALO *et al*., 2016).LIMA JUNIOR *et al.* (2016), report that to generalize these operations of aggregation of fuzzy sets, t-norm operators are used, which are based on the logical connection "E" (from the AND English), when processing the antecedent part of the inference rules, each one of them has "E" connectors that represent the relationship between the linguistic terms of the input variables, defining a union operation.For GALO *et al.* (2016), the most used operators in this case, are the "minimum" and the "algebraic product", represented respectively in Eq. (8) and (9).

$$\mu_A(x) AND \mu_B(y) = \min\{\mu_A(x), \mu_B(y)\} \quad (8)$$

$$\mu_A(x) AND \mu_B(y) = \mu_A(x) \cdot \mu_B(y) \quad (9)$$

GALO et al. (2016), further affirm, that it isit is possible to use other operators in the implication, such as, "min" and "max-min" presented by Eq. (10) to (12).

$$= \min\,(\mu_A(x), \mu_B(y)) \quad (10)$$

$$= \max\,(\min\,(\mu_A(x), \mu_B(y))) \quad (11)$$

$$= \max\,(\min\,(\mu_A(x,y), \mu_B(y,z))) \quad (12)$$

The next step is done to aggregate the outputs of the μIi (x) rules into a single fuzzy set through an aggregation operator "max", presented by Eq. (13) that can be used in this situation (GALO *et al.,* 2016).

$$= \max\,(\mu_{I1}(x),\ \ \mu_{I2}(x) \ldots \mu_{In}(x) \quad (13)$$

The defuzzification interface ends the generation of the final output of the system, where the fuzzy value is converted, due to the aggregation of the activated rules to a crisp value, that is, exact values (LIMA JUNIOR *et al.,* 2016). For FRANCE (2015), he says that among the most common methods of defuzzification that we have, the following stand out: the center of the maximum, average of the maximum and the center of gravity (centroid). Because it is more committed to the solution, the center of gravity method is more used in defuzzification, because during the calculation of the crisp output value, all pertinence values are considered, even the low ones (GALO *et al.,* 2016). Eq. (14) describes the calculation of such a method.

$$CDA = \frac{\sum_{k=1}^{n} \mu_A(x_k) x_k}{\sum_{k=1}^{n} \mu_A(x_k)} \quad (14)$$

According to LIMA JUNIOR *et al.* (2016), the most used method is the Mamdani, as it is based on a simple structure with logical operations, therefore, this model will be used in the research, as it is more appropriate in the evaluation of the various criteria for selecting suppliers, due to problem.

MATERIALS AND METHODS

Experimental methodology: In order to support decision-making in purchasing management, given the difficulty in identifying suppliers using the selection criteria in certain situations, there was a need to present a model for selecting suppliers using the fuzzy inference method, based on the studies by LIMA JUNIOR *et al.* (2013a) and GALO *et al.* (2016), defining evaluation criteria in which it demonstrates considerable social and economic elements, as the choice of these partners can cause a relevant change, such as improving the quality of products and reducing costs, making the process more efficient for the organization.The present research is considered as exploratory and classified in its nature as qualitative, in two aspects, bibliographic research with the purpose of identifying the authors' approaches to the problem in the supplier selection process, followed by the case study through simulated data, presenting a proposed model to support decision-making in purchasing management that guarantees the fulfillment of the company's needs with regard to social and economic issues in the sense of cost reduction, product quality and trust, being evaluated by specialists in the area. The method was applied to a foundation to support Research, Extension and R&D projects, located in the Center-South Zone of the city of Manaus, in Amazonas, and is linked to a Federal Institute for administrative coordination purposes. An important aspect that can be highlighted, regarding the organization is the valorization of its professionals, in the search for tools and management models that can optimize the processes in the attendance to the projects. To achieve the objective, research in the purchasing sector was delimited, observing different criteria to be adopted by the institution's professionals to improve the process.Through a meeting and interview with specialists in the purchasing area, analysis of company documents and through the bibliographic references researched, data collection was carried out, with the purpose of consolidating the theoretical and practical foundation on integrated purchasing management. in the decision making of the supplier selection process, identifying the main difficulties encountered. Through the meetings at the company, it was defined that eight main suppliers would be part of the study for the purchase of an electronic product, the choice of the material was based on the fact that it is equipment that is very requested by the foundation in attending to the projects.For the computational implementation, the Fuzzy Logic Toolbox environment of Matlab® software version 9.0 (R2016a) was used, with preliminary information that contributed to the interaction with suppliers, the use of this tool was intended to provide a broad view of the model's functioning .

Selection of criterion for supplier evaluation: The definition of methods for this case was carried out through meeting and interview with the purchasing specialists of the researched company and, through analysis, the from the simulation of the data. For the proposed model, 6 decision criteria were considered, ensuring the meeting of the organization's needs with regard to social and economic issues, as shown in Tables 6 and 7.

Table 6. Social criteria used by the company to assess suppliers

Social Criterion	Definition
Relationship with the supplier	Evaluates collaboration and trust between buyer and supplier.
Supplier profile	It comprises technical capacity, market position and financial power.
Flexibility	It consists of the ability to adapt to unexpected circumstances.

Source: Authors, (2021).

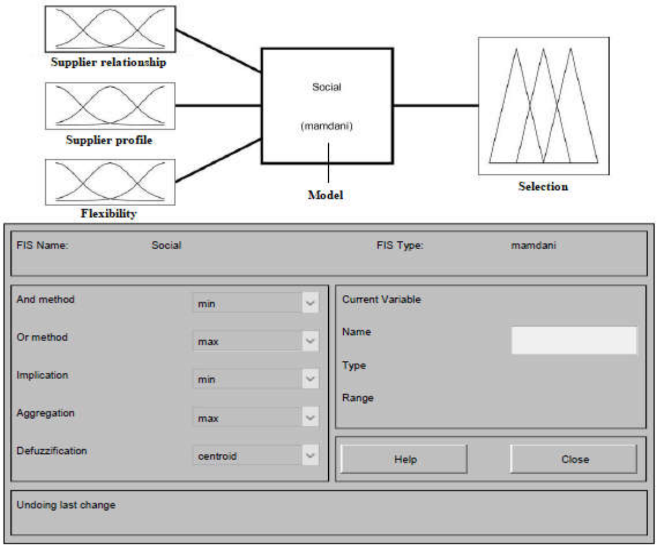
Table 7. Economic criteria used by the company to assess suppliers

Economic Criterion	Definition
Cost	Considers price, shipping cost, order processing cost and storage cost.
Quality	Performance measure resulting from a comprehensive assessment of quality management in the supplying company (skill in the production process, commitment to quality, guarantee, etc.).
Delivery	It refers to the deadline, reliability and delivery compliance.

Source: Authors, (2021).

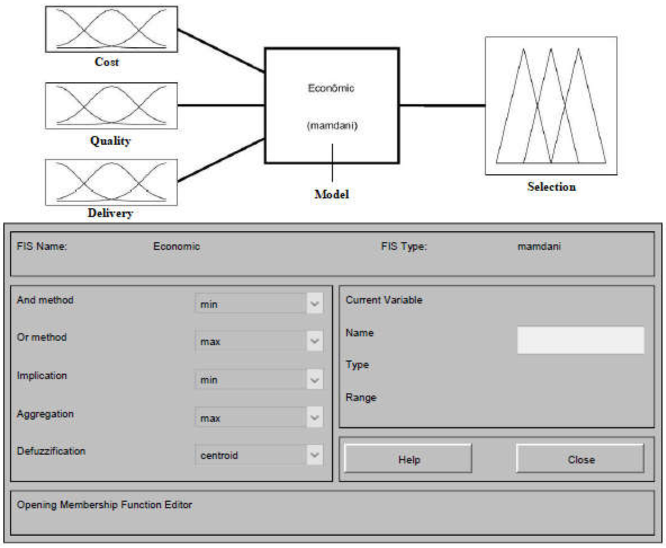
The importance and performance of the 6 chosen criteria were evaluated based on the experts' judgment, regarding the eight selected suppliers, being used as variables and their pertinence functions that according to GANGA et al. (2011), the values are represented in a qualitative way, giving characteristic to the variable through linguistic means and by a pertinence function considered quantitative, giving intensity to the linguistic values.

Analysis of the proposed fuzzy model: After analyzing the simulated data and meeting with professionals in the area to prepare the proposed model, c6 criteria were considered to ensure the meeting of the organization's needs with regard to fundamental social and economic issues, being used as linguistic variables and terms for the purchase decision. In this case, the system received a score to determine the value of each of the criteria, considered as an input variable. In Figures 7 and 8 it is possible to visualize the fuzzy inference systems implemented for the demand, representing the pertinence function applied to obtain the values seen as parameters for the evaluation of suppliers.



Source: Authors, (2021).

Figure 6. Fuzzy inference system - Social criteria



Source: Authors, (2021).

Figure 7. Fuzzy inference system - Economic criteria

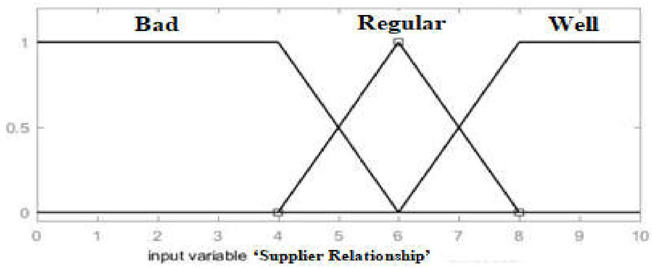
Figures 6 and 7 show the methods defined in the inference systems, using the Mamdani model, as it is more suitable for assessing suppliers by subjectivity, the "E" (AND) method, the implication operator, was used in the rules base. it was the "minimum", for the aggregation operator the "maximum" was chosen, in the defuzzification the center of gravity operator (centroid) was chosen. The variables of entry and exit of the systems are corresponded in linguistic terms and represent the mode of imprecision, being presented in Table 8.

Table 8. Variables and linguistic terms

Input language variables	Linguistic terms
Supplier Relationship (SR)	Bad
	Regular
	Well
Supplier Profile (SP)	Bad
	Regular
	Well
Flexibility (F)	Bad
	Regular
	Well
Cost (C)	Low
	Average
	High
Quality (Q)	Bad
	Average
	Well
Delivery (D)	Late
	Regular
	Fast
Output linguistic variable	Linguistic terms
Selection	Not select (NS)
	Select (S)

Source: Authors, (2021).

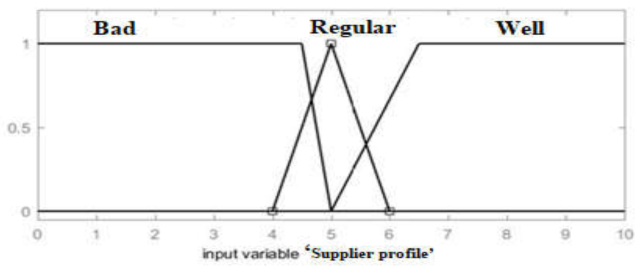
The values of the linguistic variables were defined for each input and output, measured on a scale from 0 to 10, using triangular and trapezoidal numbers. Each supplier can belong to the linguistic class "Do Not Select" (NS) or "Select" (S), considered as an output variable. The definition of the functions of the social criteria of the input variables "Relationship with the supplier", "Supplier profile "and" Flexibility",can be seen graphically in Figures 8 to 9.



Source: Authors, (2021).

Figure 8. Input variable "Relationship with the supplier" of the fuzzy inference system.

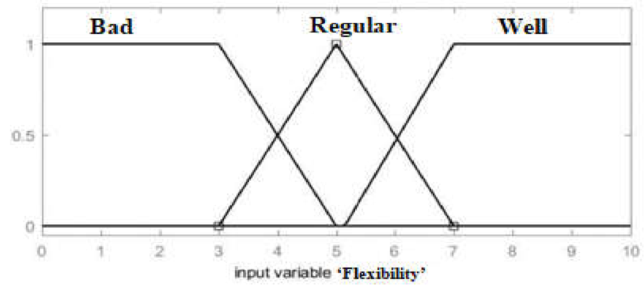
It is possible to observe in Figure 8 the input variable "Relationship with the supplier", considered very relevant, as it involves issues such as service, product or service compliance, availability, among others. Their pertinence functions were distributed with the linguistic terms "Bad", "Regular" and "Good", measured on a scale of 0 to 10 based on the studies by GALO *et al.* (2016), in addition to consultations with specialists in the field.



Source: Authors, (2021).

Figure 9. Input variable "Supplier profile"of the fuzzy inference system

In the definition of the input variable "Supplier profile", shown in Figure 9, its pertinence functions were also distributed with the linguistic terms "Bad", "Regular" and "Good", measured on a scale from 0 to 10, based on the studies by GALO *et al.* (2016), in addition to consultations with specialists in the area, being a relevant variable as it encompasses issues such as the company's potential, interests and information.



Source: Authors, (2021).

Figure 10. Input variable "Flexibility" of the fuzzy inference system

In Figure 10, the input variable "Flexibility" is presented, the linguistic terms of their pertinent functions are "Bad", "Regular" and "Good", measured on a scale from 0 to 10, based on meetings with specialists in the area and studies by GALO *et al.* (2016). It is considered an important variable, as it involves issues such as adaptation to unexpected situations, commercialization conditions, capacity to change products or services, among others.The pertinence functions of the fuzzy inference system of the input variables of the social criteria can be observed in the Tables 9 to 11.

Table 9 - Variable membership functions entry "Supplier relationship"

Fuzzy Set	Type	Parameter
Bad	Trapezoidal	[0, 0, 4, 6]
Regular	Triangular	[4, 6, 8]
Well	Trapezoidal	[6, 8, 10, 10]

Source: Authors, (2021).

In table 9, the input variable "Relationship with the supplier" has three pertinence functions, which are: "Bad" with parameter [0, 0, 4, 6], "Regular" parameter [4, 6, 8] it's good", presenting parameter [6, 8, 10, 10]. These values were defined according to the information of specialists in the area, adopting the types of trapezoidal and triangular fuzzification for simplification and for representing the functions according to the context, in addition to being more appropriate and objective to achieve optimized results in decision making.

Table 10. Variable membership functions input "Supplier profile"

Fuzzy Set	Type	Parameter
Bad	Trapezoidal	[0, 0, 4.5, 5]
Regular	Triangular	[4, 5, 6]
Well	Trapezoidal	[5, 6, 10, 10]

Source: Authors, (2021).

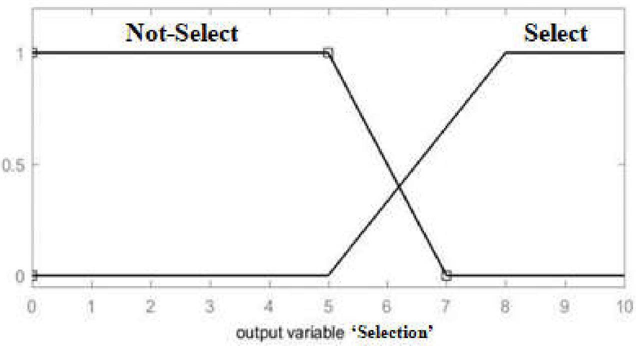
The membership functions of the input variable "Supplier profile" are three, classified as "Bad" with parameter [0, 0, 4.5, 5], "Regular" with parameter [4, 5, 6] and "Good" parameter [5, 6, 10, 10], as shown in Table 10. A definition of their values was based on the information from experts in the field, its fuzzification was trapezoidal and triangular because it is considered simpler and more suitable for obtaining optimized results in decision making.

Table 11. Variable membership functions input "Flexibility"

Fuzzy Set	Type	Parameter
Bad	Trapezoidal	[0, 0, 3, 5]
Regular	Triangular	[3, 5, 7]
Well	Trapezoidal	[5, 7, 10, 10]

Source: Authors, (2021).

The input variable "Flexibility"Presented in Table 11 has three membership functions, which are:"Bad" getting parameter [0, 0, 3, 5], "Regular" with parameter [3, 5, 7] and "Good" with the parameter [5, 7, 10, 10]. According to the information provided by specialists in the area, athe types of trapezoidal and triangular fuzzification for simplification and for representing the functions according to the context, in addition to being more appropriate and objective to achieve optimized results in decision making. It is observed graphically in the Figure 3.6 a output variable "Selection" of the fuzzy inference system of social criteria, their pertinence functions are shown in Table 12.



Source: Authors, (2021).

Figure 11. Output variable "Selection" of the fuzzy inference system - Social Criteria

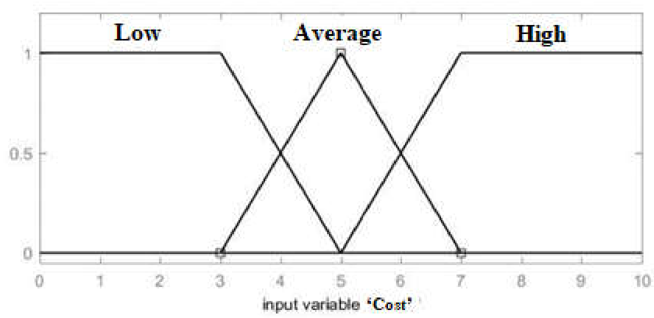
In Figure 11, the strategies that determine the output variable "Selection" of the fuzzy inference system of social criteria are presented, their pertinence functions are classified with the linguistic terms "Not Select" and "Select", measured on a scale from 0 to 10, based on the studies by GALO *et al.* (2016), in addition to consultations with specialists in the field.

Table 12. Variable membership functions "Selection" - Social Criteria

Fuzzy Set	Type	Parameter
Select None	Trapezoidal	[0, 0, 5, 7]
Select	Trapezoidal	[5, 8, 10, 10]

Source: Authors, (2021).

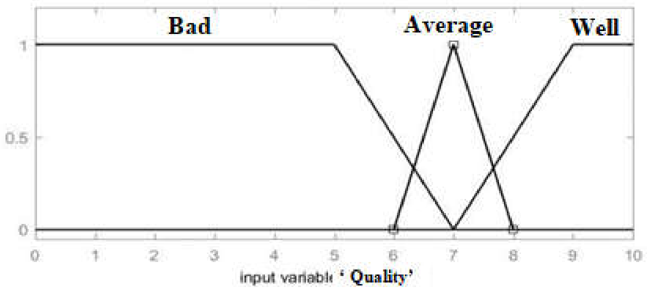
The "Selection" output variable of the social criteria fuzzy inference system, shown in Table 12, has two pertinence functions, which are: "Do not select" with parameter [0, 0, 5, 7] and "Select" with the parameter [5, 8, 10, 10], the type of fuzzification was trapezoidal, as according to experts in the field, this method is simple and represents the functions according to the context, in addition to being more appropriate and objective to achieve optimized results for decision making.Figures 12 to 14 graphically present the functions of the economic criteria of the input variables "Cost","Quality "and" Delivery ".



Source: Authors, (2021).

Figure 12. Input variable "Cost"Of the fuzzy inference system

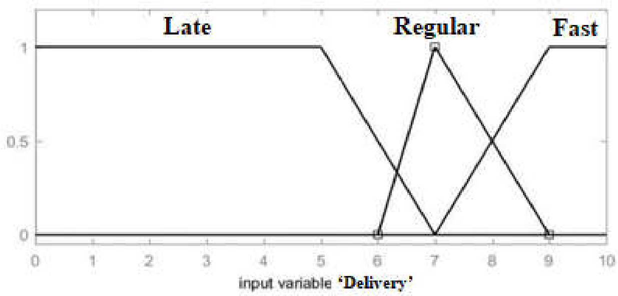
In the input variable “Cost” shown in Figure 12, its pertinence functions were defined with the linguistic terms “Low”, “Medium” and “High”, measured on a scale from 0 to 10, based on the studies by GALO *et al.* (2016), in addition to consultations with specialists in the field. The relevance of this variable is seen as high and its strategies must consider issues such as price, production values, services, transport, among others.



Source: Authors, (2021).

Figure 13. Input variable “Quality”Of the fuzzy inference system

In Figure 13, the input variable “Quality” is also considered to be of high relevance, as it involves issues such as skill, level of satisfaction, productive capacity, guarantee, commitment and others. Their pertinence functions were distributed with the linguistic terms "Bad", "Average" and "Good", measured on a scale of 0 to 10, based on consultations with specialists in the area and studies by GALO *et al.* (2016).



Source: Authors, (2021).

Figure 14. Input variable “Delivery”Of the fuzzy inference system

The input variable “Delivery”, is shown in Figure 14 and shows its belonging functions distributed with the linguistic terms “Delayed”, “Regular” and “Fast” measured on a scale of 0 to 10, based on the GALO studies *et al.* (2016), in addition to consultations with specialists in the field. It is considered a highly relevant variable as it encompasses issues such as reliability, delivery compliance, transportation, deadline and others.In Tables 13 to 15, the pertinence functions of the fuzzy inference system of the economic criteria are classified.

Table 13. Variable membership functions input "Cost"

Fuzzy Set	Type	Parameter
Low	Trapezoidal	[0, 0, 3, 5]
Average	Triangular	[3, 5, 7]
High	Trapezoidal	[5, 7, 10, 10]

Source: Authors, (2021).

Table 14 shows the input variable “Cost”, its membership functions were defined as “Low” with parameter [0, 0, 3, 5], "Medium" parameter [3, 5, 7] and "High" with parameter [5, 7, 10, 10]. YourValues were classified according to information from experts in the area, adopting the types of trapezoidal and triangular fuzzification for simplification and for representing the functions according to the context, in addition to being more appropriate and objective in decision making in order to achieve optimized results.

Table 14. Variable membership functions input "Quality"

Fuzzy Set	Type	Parameter
Bad	Trapezoidal	[0, 0, 5, 7]
Average	Triangular	[6, 7, 8]
Well	Trapezoidal	[7, 9, 10, 10]

Source: Authors, (2021).

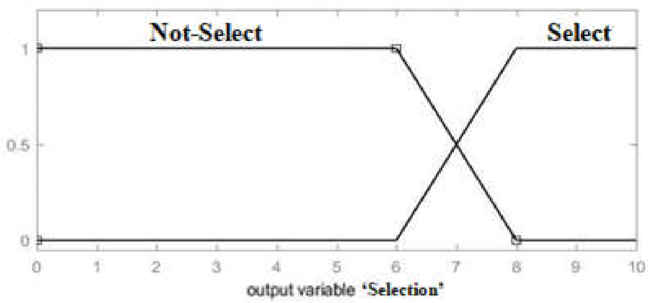
The input variable “Quality” presented in Table 14 has three pertinence functions, which are: “Bad” getting parameter [0, 0, 5, 7], “Medium” with parameter [6, 7, 8] and “Good” with the parameter [7, 9, 10, 10]. Based on information from experts in the field, the types of trapezoidal and triangular fuzzification for simplification and for representing the functions according to the context, in addition to being more appropriate and objective in decision making to obtain optimized results.

Table 15. Variable membership functions input "Delivery”

Fuzzy Set	Type	Parameter
Late	Trapezoidal	[0, 0, 5, 7]
Regular	Triangular	[6, 7, 9]
Fast	Trapezoidal	[7, 9, 10, 10]

Source: Authors, (2021).

The input variable “Delivery” presented in Table 15 has three pertinence functions, which are: “Delayed” getting parameter [0, 0, 5, 7], “Regular” with parameter [6, 7, 9] and “Fast” with the parameter [7, 9, 10, 10]. According to the information provided by specialists in the area, athe types of trapezoidal and triangular fuzzification for simplification and for representing the functions according to the context, in addition to being more appropriate and objective to achieve optimized results for decision making. The output variable “Selection” is represented graphically in the Figure 15 and its membership functions are shown in Table 3.11 of the fuzzy inference system of economic criteria.



Source: Authors, (2021).

Figure 15. Output variable “Selection" of the fuzzy inference system - Economic Criteria

The output variable “Selection” of the fuzzy inference system for economic criteria can be seen in Figure 15 and its pertinence functions were classified with the linguistic terms “Do not select” and “select” on a scale of 0 to 10, with based on the studies by GALO *et al.* (2016), in addition to consultations with specialists in the field.

Table 16. Variable membership functions “Selection” output - Economic Criteria

Fuzzy Set	Type	Parameter
Select None	Trapezoidal	[0, 0, 6, 8]
Select	Trapezoidal	[6, 8, 10, 10]

Source: Authors, (2021).

Table 16 presents the output variable “Selection” of the fuzzy inference system of the economic criteria, its pertinence functions were described as “Do not select” with parameter [0, 0, 6, 8] and “Select” with the parameter [6, 8, 10, 10], the type of trapezoidal fuzzification as it is simpler and suitable for the context, according to experts in the area, facilitating the achievement of optimized results in decision making. The number of pertinent functions for each input linguistic variable presented, multiplied, results in the number of fuzzy rules that will compose the rule base of the proposed model.

Table 17. Fuzzy inference rules - Social criteria

SE				THEN
Rule	**SR**	**SP**	**F**	**Selection**
1	Bad	Bad	Bad	Select None
2	Bad	Bad	Regular	Select None
3	Bad	Regular	Bad	Select None
4	Regular	Bad	Bad	Select None
5	Regular	Regular	Bad	Select None
6	Regular	Bad	Regular	Select None
7	Bad	Regular	Regular	Select None
8	Well	Bad	Bad	Select None
9	Bad	Well	Bad	Select None
10	Bad	Bad	Well	Select None
11	Regular	Regular	Regular	Select None
12	Regular	Regular	Well	Select
13	Regular	Well	Regular	Select
14	Regular	Well	Bad	Select None
15	Well	Regular	Regular	Select
16	Regular	Regular	Bad	Select None
17	Regular	Bad	Well	Select None
18	Well	Bad	Regular	Select None
19	Bad	Well	Regular	Select None
20	Well	Well	Well	Select
21	Well	Well	Regular	Select
22	Well	Well	Bad	Select None
23	Bad	Regular	Well	Select None
24	Regular	Well	Well	Select
25	Bad	Well	Well	Select None
26	Well	Bad	Well	Select None
27	Well	Regular	Well	Select

Source: Authors, (2021).

Table 18 shows the parameterization of the rule base for the fuzzy inference of the economic criteria.

Table 18. Fuzzy inference rules - Economic criteria

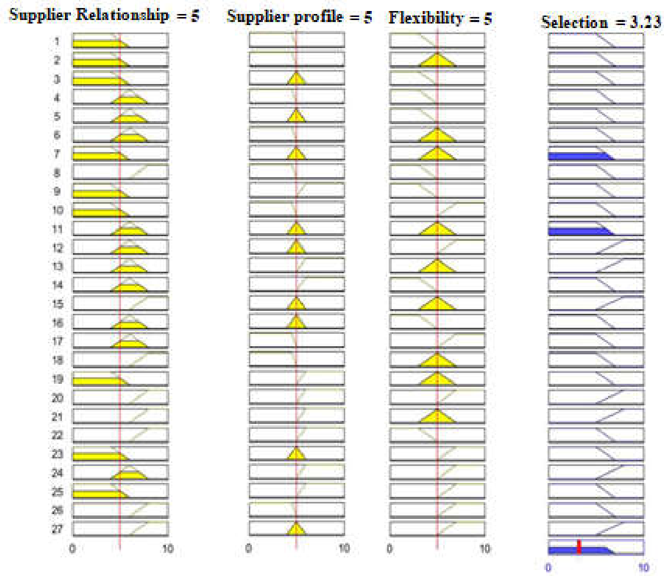
SE				THEN
Rule	**Cost**	**Quality**	**Delivery**	**Selection**
1	Low	Bad	Fast	Select None
2	Low	Bad	Regular	Select None
3	Low	Bad	Late	Select None
4	Low	Average	Fast	Select
5	Low	Average	Regular	Select
6	Low	Average	Late	Select None
7	Low	Well	Fast	Select
8	Low	Well	Regular	Select
9	Low	Well	Late	Select None
10	Average	Bad	Fast	Select None
11	Average	Bad	Regular	Select None
12	Average	Bad	Late	Select None
13	Average	Average	Fast	Select
14	Average	Average	Regular	Select
15	Average	Average	Late	Select None
16	Average	Well	Fast	Select
17	Average	Well	Regular	Select
18	Average	Well	Late	Select None
19	High	Bad	Fast	Select None
20	High	Bad	Regular	Select None
21	High	Bad	Late	Select None
22	High	Average	Fast	Select None
23	High	Average	Regular	Select None
24	High	Average	Late	Select None
25	High	Well	Fast	Select None
26	High	Well	Regular	Select None
27	High	Well	Late	Select None

Source: Authors, (2021).

Thus, this calculation generated a total of 27 rules for each system, being (3 x 3 x 3) for social criteria and (3 x 3 x 3) for economic criteria, making the implementation of the model viable. These rules were formatted using the if-then structure.It is possible to see in Table 17 the parameterization of the rules base of the fuzzy inference of the social criteria.The data were simulated according to the attributes presented by the eight selected suppliers. In the inference systems the input values were inserted as fuzzy variables for the final calculation of the scores, being evaluated according to the rules base, using the “E” (AND) method, the “minimum” operator, the implication operator it was also the “minimum”, the aggregation operator chosen was the “maximum”, for the defuzzification, we opted for the center of gravity operator, also called centroid.

RESULTS AND DISCUSSIONS

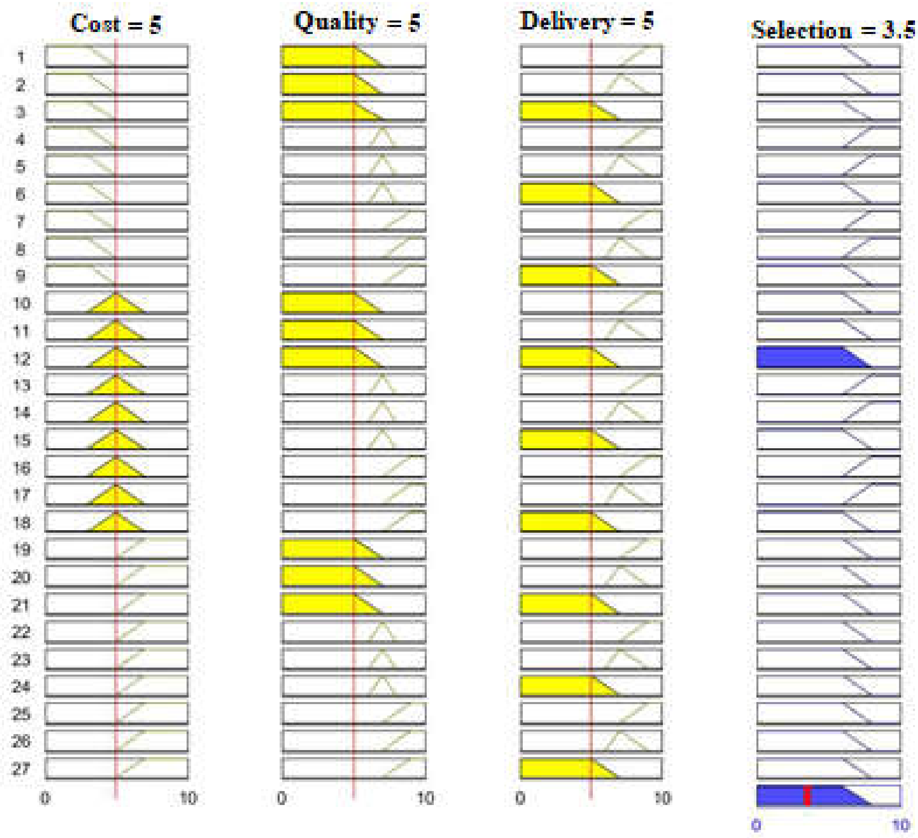
Applying the results: The study sought to propose a model for selecting suppliers, aiming to improve the purchasing process. After application, the data presented proved to be satisfactory for specialists in the area, as it allows the variation of the input values and the evaluation of the outputs, allowing a correct and efficient analysis to support decision making. Two systems were developed for analysis, using Matlab® software version 9.0 (R2016a), using the Fuzzy Logic Toolbox tool, taking into account the social and economic criteria for a possible purchase of a very relevant electronic product in the researched company. input variables for the simulation of the fuzzy system process, where the result served as a reference in the assessment of suppliers. After defining the input variables, the inference model used to calculate the numerical value of the output variable was Mamdani and, for defuzzification, the center of gravity (centroid) method was adopted, as it ensures a smooth and continuous control surface that calculates the center value mass (crisp) for its pertinence, which according to CHERRI *et al.* (2011), the contribution of each activated rule is combined and its output is the set that divides the area into two parts, considering all the pertinence values. Figure 16 shows the estimation of the values of the pertinence functions of the input variables of the fuzzy inference system for social criteria, based on the 27 established rules.



Source: Authors, (2021).

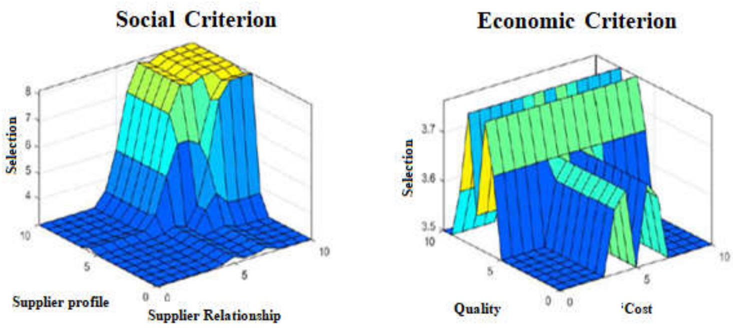
Figure 16. Functions of membership of the input variables of the fuzzy inference system - Social Criteria

Figure 17 shows the estimation of the values of the pertinence functions of the input variables of the fuzzy inference system for the economic criteria, based on the 27 rules established.According to the data presented in Figures 16 and 17, it is possible to verify the fuzzy inference process for the input scores, analyzing the performance of the suppliers, each line represents a system decision rule.



Source: Authors, (2021).

Figure 17. Functions of membership of the input variables of the fuzzy inference system - Economic Criteria



Source: Authors, (2021).

Figure 18. 3D surface graph of the input and output variables of the fuzzy inference system

Table 19 - Scores of suppliers - Social and Economic Criteria

Supplier	Social			Economic		
	SR	SP	F	C	Q	D
F_1	6.37	5.53	6.3	7.06	6.43	5.5
F_2	7.2	8.06	7.54	6.06	6.4	6.37
F_3	3.85	4.31	4.08	4.83	3.02	6.83
F_4	8.21	7.21	9.05	5.96	5.91	4.79
F_5	7.6	8.36	8.21	5.29	6.82	8.87
F_6	4.77	5	5.23	4.71	7.48	7.12
F_7	8.97	8.59	6.3	5.13	7.07	6.87
F_8	7.67	7.44	7.14	4.62	8.31	7.62

Source: Authors, (2021).

The first three columns on the left refer to the input variables and their linguistic terms, the fourth column displays the output variable. The fuzzy sets stimulated by the scores correspond to the yellow part and should be taken into account at the time of the assessment, the column highlighted in blue refers to the fuzzy sets that are generated when each rule is activated, after the value is shown after defuzzification. The vector of the input variables of the two implemented systems is 10, for each of them, and the selected ones could reach a minimum score, which is 5, presented in the models, serving as a parameter at the time of the evaluation. Rules 7 and 11 of the social criteria and 12 of the economic criteria were activated, adding the output indicated at the end of the last column, pointing out the values 3.23 and 3.5, corresponding to the defuzzification, which must be seen at the time of the analysis to assess the scores of the Providers. After the rules are activated, the data can be simulated in 3D, as shown in Figure 18.The graph in figure 18 shows the visualization of the surface of the mapping of the input and output variables of the systems to the social and economic criteria. The input variables are analyzed in combinations of different pairs in the horizontal part and the output variable can be seen in the vertical part.

Evaluation of selected suppliers: The elaboration of the supplier selection model was based on the requirements defined by the specialists of the studied company. After obtaining information, the values established for each criterion were generated in both systems as a reference in the assessment of suppliers. In Table 19 the values of these scores are presented.The scores were estimated for each of the eight chosen suppliers, and the input values for calculating the final scores for each of the attributes were inserted in the fuzzy inference systems. The "E" (AND) method was used, the "minimum" operator of implication and the "maximum" operator of aggregation, for the defuzzification, the center of gravity or centroid operator was chosen. The results for the inferences of the social and economic criteria can be seen in Table 20.

Table 20. Result of suppliers' final scores - Social and Economic Criteria

Supplier	Social		Economic	
	Performance	Selection	Performance	Selection
F_1	5.51	s	3.76	NS
F_2	7.94	s	5	s
F_3	3.21	NS	3.58	NS
F_4	8.17	s	3.72	NS
F_5	8.06	s	7.04	s
F_6	3.62	NS	8.27	s
F_7	7.97	s	7.77	s
F_8	8.08	s	8.33	s

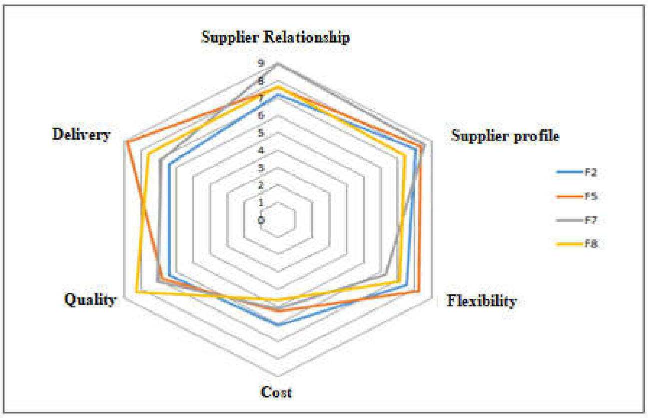
Source: Authors, (2021).

Analyzing the results of the exit scores of the two systems for the social and economic criteria, as well as the performance of each one, it is noted that the suppliers are able to be selected by the purchasing company and must maintain the relationship with them, being considered potential partners in the development of new acquisitions. For the identification of the best alternatives, the ordering of the suppliers was made, with the weight being classified for each criterion. In this case, weight 2 was assigned to social criteria and weight 3 to economic criteria, calculating the final values using a weighted average. Thus, in Table 21 it is possible to obtain the results presented.F_2, F_5, F_7 e F_8

Table 21. Final score and placement of selected suppliers - Social and Economic Criteria

Supplier	Social	Economy	Performance	Placing
F_2	7.94	5	6.17	4th
F_5	8.06	7.04	7.44	3rd
F_7	7.97	7.77	7.85	2nd
F_8	8.08	8.33	8.23	1st

Source: Authors, (2021).



Source: Authors, (2021).

Figure 19. Radar chart, shows the evaluated criteria, highlighting the supplier F8 as the first placed

Therefore, after the results shown in Table 21, it was observed that the final order of the suppliers obtained was, but it is important to note that the displayed values were very close, presenting a minimum distance from one supplier to the other, the first being placed had a difference of 0.38 from the second, the distance from the third was 0.79, in relation to the fourth placed, the difference was 2.06 compared to the first, classified as the longest distance compared to the other suppliers. Therefore, in this case, for the performance of the best supplier, it is valid for the company to select the alternative that stands out in a certain criterion that the specialist evaluates as the most important. This behavior is seen in a positive way, since the difference is minimal between one supplier and another, which results in the continuity of the relationship with them, in the development of new acquisitions. The performance of the four best suppliers is presented graphically in Figure 19 for the evaluated criteria, highlighting the supplier as the first placed.$F_2 < F_5 < F_7 < F_8 F_8$ According to the results obtained, it was noted that half of the evaluated suppliers did not achieve a good performance, as they presented high costs, the quality of the product was inferior, even because it did not maintain a good relationship with the purchasing company. Based on this information, it is valid to develop techniques for analyzing critical activities to be used when assessing each supplier, and the use of tools to recover those who have not presented good results, in addition to developing new ones, Providers.

CONCLUSION

The study aimed to propose the use of fuzzy inference in the supplier selection process, as it has been shown to be a fundamental step for organizations, ensuring their competitiveness, considering different social and economic criteria that impact on product acquisitions and contracting services in the search for lower costs and a high level of satisfaction. The model was developed in Matlab® software version 9.0 (R2016a), using the Fuzzy Logic Toolbox environment, allowing this tool to become practical and quickly applicable to the needs of the purchasing sector, obtaining a good interaction with the user. The grouping of the data presented some different results in relation to each analyzed variable, seen as the effect of the set of these variables. Information collected by the specialists was submitted, generating values for comparison of each selected supplier. After data obtained in the analysis, it was observed that the model presented relevant data for their comparison, where the difference was minimal for each supplier evaluated. Since the first place obtained a difference of 0.38 from the second, the distance from the third was 0.79, with respect to the fourth placed the difference was 2.06 compared to the first, classified as the longest distance compared to the other suppliers. This behavior is seen in a positive way, since the difference is minimal between one supplier and another, which results in the continuity of the relationship with them, in the development of new acquisitions. Based on this information, it is valid to develop techniques for analyzing critical activities to be used when assessing each supplier, and the use of tools to recover those that have not presented good results should also be adopted, in addition to the development of new ones. Providers. The research demonstrated the application of the proposed model in a supplier selection process for a foundation to support various projects, making it more competitive. The benefits achieved by the organization also include the specialists who participated in the study who obtained advantages due to the interest in carrying out good practices with the presented method.
Therefore, this work can serve as a reference for new studies on the topic presented through this research, which regardless of the branch of the company, the fuzzy inference model can be considered a great tool for decision making, increasing the competitiveness of the business.

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