Suppliers Analysis and Selection to Improve Supply Chain Performance

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Abstract. Having good suppliers not only means having quality supplies, it also means having low costs. Suppliers play a fundamental role in the production process from the acquisition of raw materials and even in the design and innovation of products. After an analysis of the literature related to the objective of the research, this article proposes a methodology for the analysis and selection of suppliers in order to improve the performance of the supply chain and also to be able to face the diversity and complexity of the situations that may arise in the purchasing process. The article provides professionals with flexibility and effectiveness in the selection of suppliers and their selection process, and with a better understanding of their future purchasing strategies. The fundamental findings of this research focus specifically on the determination and analysis of the main methods quantitative used in the selection of the supplier. The proposed methodology is applied in a company in the automotive sector and there is a good expectation of the methodology since in the preliminary investigations satisfactory results have been obtained.

Keywords: Suppliers · Supply chain · Selection process · Quantitative methods

1 Introduction

Nowadays, internationally successful companies are supplying the world's best competitive advantages [1], making it vitally important for them to develop competitive strategies based on value aggregation and simultaneous cost reduction [2]. As well as integrated management of supply-manufacturing-distribution tertiary and effective integration into international marketing networks [3]. For that reason, suppliers and customers must be partners in supply chains and not be faced with isolated authorities. Having good suppliers can not only mean having quality inputs and, therefore, being able to offer quality products, but also these give companies the possibility of having low costs, or the security of always having the same products whenever they are required [4]. In the case of the automotive sector, suppliers play a fundamental role in the process from the acquisition of raw materials to even the design and innovation of products.

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According to the analyzed literature, within the common problems, as a result of the poor selection of suppliers in the automotive sector, approximately 43% are associated with supply problems, therefore, our study will focus on this problem. The deficiency in supply in a factor that negatively affects the production process by increasing its variability and increasing the risks of obtaining a product without the spices requested by the customer [5]. Inadequate supplier selection could also have a negative impact by bringing with it increased costs, late deliveries of products, incomplete deliveries and elongation of cycles [6]. The objective of this article is to propose a methodology for the analysis and selection of suppliers within the automotive sector to improve the performance of the supply chain. In order to comply with our objective, it is essential to investigate about the processes for the selection of suppliers, which methodology has been used in the literature, as well as what criteria have been managed and which tools have been developed.

Supplier selection should have as its main criterion the ability of the supplier to improve and work under collaborative policies, without neglecting the characteristics traditionally valued such as price, quality, delivery time and payment plans [7]. Supplier selection is a multi-criteria problem, which includes quantitative and qualitative factors [8], so to select the best supplier it is necessary to make compensation between several factors. It is not easy to make the decision about which is the best supplier and therefore methodologies have been developed to help in this process.

For the supplier selection process, [9] proposes that firstly, the problems and objectives pursued by the company must be identified. Then, to determine the selection criteria according to the entity's own needs and later to select and apply a selection method.

There are multiple criteria to consider for the selection of the right suppliers for the logistics process of companies. They range from presenting attractive prices of the products, raw materials, or services they provide, delivery at the necessary time and to providing a quick response to some inconvenience. In a complex decision environment such as that surrounding supply chain management, cost- and price decisions proposed by the supplier are somewhat dangerous if they are not based on a comprehensive analysis of the economic context, existing restrictions and dominant business practices such as thorough market research [10]. For this reason, the complexity of a supply process should consider a set of variables related to transport, market fluctuations, costs, quality requirements, negotiation processes and inspection procedures.

Once the criteria are identified, the next step is to choose the suppliers by applying a certain method. The selection method must be consistent with the analysis of the context, the realities of the supply chain the selected criteria. Depending on the method selected, the efficiency of the purchase decision can be increased by enabling faster and more automated processing of data, eliminating redundant criteria and alternatives in decision-making processes, and facilitating more effective communication [11]. In the literature we can find referenced several methods that have been used for the selection of suppliers. These can be classified or grouped into Mathematical Methods, Statistical Methods, Artificial Intelligence Methods, and Integrated Methods which is the combination of 2 or more methods from the above classifications [12].

This article is organized as follows. The next section will discuss the background of the investigation where it will be presented, among other things, what methodologies

they have used for the selection of suppliers, the main selection criteria, as well as the tools used. Subsequently as a conclusion we will analyze the methodology that we propose in this article.

2 Background

Within this field of supplier management, a significant number of contributions are in the specialized literature that are oriented to the development of three fundamental topics: (1) supplier management as part of supply chain management, (2) suppliers selection as a strategic decision and (3) techniques and methods to support the decision to select suppliers [7].

The management of an efficient supplier system as a link in the supply chain is considered one of the most impact and complex logistical tools in sourcing operations in companies. Supplier management is a key element in the modern administration of organizations, especially when the quality of what enters the process is considered to affect the quality of the outputs, which is a potential when it comes to improving the purchasing system associated with efficient supply chains [11]. For this reason, it is essential that companies have a process of selection of suppliers that analyze different aspects that result in the selection of the best partner.

2.1 Methodologies for Supplier Selection Processes

For decades, researchers and professionals from various branches have paid close attention to the selection of suppliers and the methods to be able to select them properly. Supplier selection is a multi-crime problem, which includes quantitative and qualitative factors. To select the best supplier, it is necessary to make a compensation between these tangible and intangible factors between which there may be conflict [11]. It is not easy to make the decision about which is the best supplier and therefore methodologies have been developed to help in this process.

In the case of Vírseda, 2011 [9], it proposes a supplier selection process comprising 4 fundamental steps: Assessing needs and defining objectives; Gather a group of suppliers; Interview with suppliers; Select and apply a method.

In the first step in assessing the company's needs and the corresponding requirements for contacting the appropriate suppliers, it proposes that a list should be created with the selection criterias that are taken to evaluate suppliers. The second step of bringing together a group of suppliers is to be done through a "request for information" (RFI) to learn more about these companies, as well as through previous market research. Once all the proposals are received from the suppliers, the company makes a technical and commercial evaluation. Each company uses a different way of evaluating and selecting suppliers through different methods. Finally, a supplier is selected, and the terms of delivery and service are negotiated.

On the other hand, [13] emphasizes that the vendor selection process can include several stages such as the following:

1. Recognize the need for supplier selection, i.e. determine what factors have been presented in companies that have led to problems in the entity.

2. Identifying key requirements of those depends on business objectives.
3. Determine sources of supply or supplier selection criteria.
4. Limit suppliers in selection group or what is the same, determine a portfolio of suppliers.
5. Determine the method of evaluation and selection of the supplier.
6. Select vendor and make an agreement.

The methodology proposed by [14] is also robust, because it defines different steps for the supplier selection process that take into account the diversity and complexity of the situations that may arise in the purchasing process and the importance of taking it in bill.

The four stages defined by Boer [14] are as follows:

a) Defining the problem
b) Determination of the attributes to be evaluated
c) Evaluation of suppliers using a technique and
d) Final selection of the supplier.

As for the definition of the problem, the author argues that it is necessary to understand the problem through certain questions such as: What is the life cycle of the product or component? Why is there a need to select a new provider? What have been the problems you have had with previous suppliers? To determine the attributes to be evaluated the author proposes that they can be classified into quantitative attributes (which can be measured by a previously established scale), or qualitative attributes (cannot be expressed by a unit or measurement scale so evaluation and experience of people who know the problem is required). These attributes or criteria must be selected according to the needs of the company. Once the criteria are defined, the next step is to choose suppliers by applying a certain method that must be consistent with the analysis of the context, the realities of the supply chain and the selected criteria.

2.2 Supplier Selection Criteria

As discussed in the previous section and in the examples above, one of the main aspects of the vendor selection process is the selection criteria.

The selection of suppliers constitutes a strategic decision with a high impact on the performance of the organization, for this reason it is considered necessary to select the right supplier, in favor of strategic development and according to the specific needs of the company [15]. Resources are directed only to working with those suppliers with whom we can obtain significant and valuable value [4].

There are multiple criteria to be able to select the right suppliers for the logistics process of companies. They range from presenting attractive prices of the products, raw materials, or services they provide, to providing a quick response to some inconvenience. In a complex decision-making environment, decisions based only on the price proposed by the supplier and costs are somewhat dangerous if they are not based on a comprehensive analysis of the economic context, existing restrictions and dominant business

practices [7]. An important point to note is that some criteria are often in conflict with each other, as the increase of one characteristic may mean the decrease of another [11].

Each of these aspects must be selected according to the needs of the business, i.e. they are inherent to each product supplied and are of great importance within the selection model. In literature and in practice, the most used criterias for supplier selection are quality, sales price, and delivery times, however, there are many other criteria within these criteria we cite the following:

- Certified quality management system: The supplier must demonstrate its ability to establish, document and implement an effective quality management system.
- Administrative capacity: The main thing is that suppliers have administrative maturity that allows them to establish a cooperative and society relationship based on maintaining optimal levels of quality, costs and services.
- Business performance: The company requires a supplier that is profitable for it, in terms of discounts and payment terms. This aspect, typical of each supplier, demonstrates its commercial stability and provides a confidence support in economic terms.
- Financial stability: Suppliers have a stable and sound financial position, which is a good indicator when making long-term negotiations.
- Treatment of complaints and complaints: The supplier must develop effective strategies to resolve complaints and concerns, investigate their causes and therefore improve the service provided to the company on an ongoing basis.
- Geographical positioning, distribution centers and technical support: The entity must have efficient suppliers, considering that geographical positioning can influence delivery times, cost in freight-insurance and legal documentation.
- Processing of information in online order handling: Suppliers must have a reliable information handling system to observe the compliance status of purchase orders, shipments and inventory system. You need to select suppliers that are related to the research and development of your products and services.
- Installed production capacity: Knowing capacity is essential for business management as it allows to analyze the degree of use of each of the resources in the organization and thus can optimize them.
- Technical Product Specifications: The supplier must ensure that the product you provide meets all specifications included in the purchase order. Material certifications containing the results measured during production are required.
- Sales price: Suppliers are required to have stable behavior in relation to the fluctuation in the price of the products offered and in addition that the prices provided by the supplier are competitive according to the market.
- Logistics performance: Each supplier must ensure that logistics development activities are planned and carried out during the stages of the product lifecycle, thus ensuring the satisfaction of the specifications requested by the company in all aspects [7, 11].

On the other hand, supplier selection should have as its main criterion the ability of the supplier to improve and work under collaboration policies, without regard to the characteristics assessed above, among others. Logically, not all attributes are equally

important to all companies. As mentioned above, each company is a special case that presents its own needs and that can face different problems (Molamohamadi et al. [16]).

3 Quantitative Methods Used for Supplier Selection

Another fundamental aspect of the supplier selection process is to choose them by applying a method. This, once the criteria are identified. The selection method must be consistent with the analysis of the context, the realities of the supply chain and the selected criteria.

It is recurring then to know some of the tools or methods that have been used in this regard. The techniques used for vendor selection in general can be classified or grouped into Mathematical Methods, Statistical Methods, Artificial Intelligence Methods, and Integrated Methods which is the combination of two or more methods from the above classifications. Will be analyzed some of these methods below.

3.1 Mathematical Methods

For a long time, the methods that have been used most for the selection of suppliers are mathematical methods, since the main objective of numerical analysis is to find "approximate" solutions to complex problems using only arithmetic operations. In this section we introduce some of these techniques.

Analytic Hierarchy Process (AHP)
Within Mathematical Methods, the Analytical Hierarchy Process or AHP is one of the most widely discussed methods in both supplier selection and general. It was introduced by [17],and is a measurement theory that provides the ability to incorporate both qualitative and quantitative factors into the decision-making process. It therefore facilitates decision-making by organizing criteria or judgments into a hierarchical multi-level structure that exhibits the forces influencing a decision [18]. [19] define AHP as a decision-making method for prioritizing alternatives when multiple criteria should be used. In addition, we can say that the AHP generates numerical priorities based on subjective criteria and organizes them into paired comparison matrices. His greatest strength lies in his ability to hierarchically structure a complex, multi-goal problem and then investigate each level of hierarchy separately [7]. From the analyzed literature, it can be said that this is the most used quantitative tool for the suppliers' selection.

Linear Programming (LP)
Linear programming has also been used in this field. It is a widely used methodology based on mathematical models and sometimes complex systems of equations. It was created to give a practical and resource optimization sense in the quest to obtain a better and more concrete solution, as is the case in the allocation and distribution of resources when these are limited [20]. We can also say that Linear Programming is a technique that is used to optimize a function subject to constraints, this with the aim of identifying possible results or combinations for the best decision [21]. In other words, Linear Programming is an optimization method in the sense of reaching a more

appropriate result. It then aims to solve problems and determine the best combination of activities to optimize resources and use only what is necessary, this technique is designed to support managers in planning and decision-making [22].

Goal Programming (GP)
Goal Programming is in a linear programming extension to deal with problems with multiple, usually conflicting targets. It allows decision makers to set their suction levels for each target [23]. It is also the most widely used approach in the field of decision-making with multiple criteria that allows the decision-maker to incorporate numerous variations of constraints and objectives and aims to minimize the deviation between the achievement of the objectives and their aspiration. It can be said that GP has been, the most widely used multi-goal technique in management science due to its inherent flexibility in managing decision-making problems with various objectives to be addressed [24].

Data Envelopment Analysis (DEA)
Data Envelopment Analysis is another mathematical method used for supplier selection, it is a mathematical linear programming technique that calculates the relative efficiency of multiple decision-making units, based on multiple inputs and multiple outputs, without needing to know any functional relationship between them. DEA is based on the concept of efficiency of a decision alternative. Alternatives are evaluated in terms of cost-benefit ratio [11]. According to De Boer [14], efficiency is measured from the value ranging from the average sum of profits to the values of the cost criteria. This method allows suppliers to be classified into two initial categories: efficient suppliers or inefficient vendors. This tool can be applied in multipurpose troubleshooting.

Simulation
Simulation is another mathematical method used for supplier selection, which to a lesser extent. Simulation is a tool whereby both new and existing processes can be projected, evaluated and contemplated without risk, associated with experiences carried out in a real system. In other words, it allows organizations to study their processes from a systematic perspective by seeking a better understanding of the cause and effect between them in addition to allowing a better prediction of certain situations [25]. Simulation models can be classified into Static, Dynamic, Deterministic, Stochastic, Discrete, Continuous, Physical, Analog, or Symbolic [14, 26]. For supply chain optimization professionals, a major difficulty is the uncertainty and dynamics that occur along supply chain, therefore simulation, due to its ability to handle variability, is a very popular tool for these systems. Discrete event simulation is one of the most widely used and accepted tools in supply chain analysis [27].

Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)
PROMETHEE is a method for evaluating alternatives to decision-making with multiple criteria. It is characterized by many types of preference functions that are used to assign differences between alternatives in trials [28]. We can also say that PROMETHEE is a classification method that is considered simple in conception and calculation compared

to many other multicriteria decisions methods. It is well adapted to decision problems where a finite set of alternatives must be exceeded subject to multiple criteria [29] and is based on peer comparisons of alternatives with respect to each criterion. It is also a method that can be applied to real-life planning problems such as business, government institutions, transportation, health care and education [28]. In short, PROMETHEE helps decision makers find the alternative that best suits their goal and understanding of the problem. It provides an integral and rational framework for structuring a decision problem, identifying and quantifying its conflicts and associations, working groups, and highlighting the main alternatives with structured reasoning [30].

3.2 Statistical Methods

Cluster Analysis
In this respect we should point out Cluster Analysis, which is a very important technology. Its primary goal is to divide a large amount of unprocessed data into multiple groups according to evaluation rules so managers can use split groups for decision making. The purpose is to differentiate the grouped data by calculating similarities between data or following other evaluation rules so that differentiated data can form multiple groups that are characterized by high similarity of data in the same group. Supplier cluster analysis is an important procedure in building a supply chain system as selecting the right supplier group could strengthen operational capacity and reduce business risks [31].

3.3 Artificial Intelligence Methods

Artificial Intelligence (AI) is one of the branches of computer science that has aroused the most interest today, due to its huge field of application. The search for mechanisms that help us understand intelligence and make models and simulations of them, is something that has motivated many scientists to choose this area of research.

Artificial Neural Networks
Among the Artificial Intelligence methods used in the literature for the suppliers' selection is Artificial Neural Network. These are but an artificial and simplified model of the human brain, which is the best example that we have for a system that is able to acquire knowledge through experience, that is to reproduce certain characteristics typical of humans, such as the ability to memorize and associate facts. A neural network is a new system for the treatment of information, whose basic processing unit is inspired by the fundamental cell of the human nervous system: the neuron [32]. Therefore, Neural Networks consist of processing units that exchange data or information, are used to recognize patterns, including images, manuscripts, and time sequences (e.g. financial trends). They can learn and improve their functioning [33].

Analytic Network Process (ANP)
Another mathematical method that has been used in the literature for supplier selection is the Analytic Network Process, which is a generalization of the AHP and can be used to treat more sophisticated decision problems than AHP [11]. The ANP provides a general

framework for handling decisions without assuming about the independence of the top-level elements of the lower-level elements and on the independence of elements within a level. Therefore, ANP is represented by a network without the need to specify levels as in a hierarchy [19]. The elements of the network influence each other, which the decider values by paired comparisons whose intensity is measured on Saaty's 1–9 scale. [11]. In other words, by using the ANP, we can model dependencies and feedback between decision-making elements, and calculate more accurate criteria weights and local and global alternative priorities [17].

Fuzzy Set Theory (FST)
In the literature we can also find a method called Fuzzy Set Theory (FST), which allows to represent common knowledge, which is mostly of the qualitative linguistic type and not necessarily quantitative, in a mathematical language [11]. This method should be used to process inaccurate data and inaccurate information obtained from complex situations that cannot reasonably be described in conventional quantitative expressions [34]. Therefore, FST allows a generalization of the concept of classic set for modeling complex and poorly defined systems. The main concepts associated with FST, as applied to membership functions, linguistic variable, natural language computing; arithmetic operations of fuzzy sets and fuzzy weighted average, among others [35].

Case Based Reasoning (CBR)
Another method is Case Based Reasoning. This is an administrative software system by a database that collects relevant information from decision-making processes and evaluation of previously occurred situations or cases. In this way the decision maker can rely on useful information and experiences of known situations. The CBR allows for successful procurement management, as it has the advantage that by taking into account the progress made in previous processes, it does not give room for the same mistakes to be made again, especially because it reuses relevant information in evaluations that suppliers have made previously [11]. In other words, a CBR system is a software-based database that provides useful information and experiences from previous decision-maker situations like a decision maker [14].

Expert System (ES)
Expert System is one of the successful fields of application in Artificial Intelligence. It is a knowledge-based system that uses an inference procedure to solve problems that would otherwise require human competence or experience. The power of expert systems comes primarily from specific knowledge about a narrow domain stored in the knowledge base. Therefore, expert systems use human knowledge to simulate expert performance, and present a human facade to users. Expert systems can advise, instruct and assist humans in decision-making, justify a conclusion and suggest alternatives to a problem [36].

As mentioned above, these are some of the methods that have been used for vendor selection. The integration of several methods discussed above has also been used for this. A summary of these is referenced in the Table 1.

On the other hand, it is important to point out some problems that have arisen within organizations due to the inadequate supplier's selection. Such as the financial problems, operation of the logistics system, deficiency in the supply of raw materials and supplies

Table 1. Methods used for supplier selection

Methods		Authors
Mathematical	Analytic Hierarchy Process (AHP)	Yadav & Sharma (2014)
	Linear Programming (LP)	Talluri et al. (2005)
	Goal Programming (GP)	Azmi, & Tamiz (2014)
	Data Envelopment Analysis (DEA)	Garfamy (2006)
	PROMETEE	Abdullah et al. (2018)
	Simulation	Salmasnia et al. (2018)
Statistical	Cluster Analysis	Che & Wang (2009)
Artificial intelligence	Artificial neural networks (ANN)	Fernández et al. (2009)
	Case Based Reasoning (CBR)	Zhao & Yu (2011)
	Expert System (ES)	Chen et al. (2006)
	Fuzzy set Theory (FST)	Florez-Lopez (2007)
	Analytic Network Process (ANP)	Sarkis et al. (2002)
Integrated	AHP, DEA	Ramanathan (2007)
	AHP, GP	Kull et al. (2008)
	FUZZY, AHP	Kumar & Garg (2016)
	Simulation, DEA	Azadeh & Zarrin (2014)
	Artificial neural networks, AHP, DEA	Ha et al. (2008)

for production, delivery of defective and incomplete products or inadequate services and loss of customers by not following up on claims, among others that may arise.

Within the analyzed literature that deals with the topic of provider analysis and selection, the most used method is AHP, however, other methods such as ANP, Neural Networks and integrated methods have also been recently used by authors and researchers. Although in the coming years it is to be expected the use of many more tools for the development of investigations

In order to argue the above, in the Table 2 has been drawn up with some of the researchers who have addressed the topic of supplier selection, the problems that have been developed, the methods used for the solution of the same, as well as the benefits they provided.

Table 2. Relationship of some problems derived from the inadequate selection of suppliers in the automotive sector, some authors and the methods used.

Authors	Methods	Problems	Advantage
Galankashi, MR et al. (2016)	AHP, FUZZY	Finance	Flexibility for attribute selection and weighted judgment on the importance of criteria
Gómez, J. C. et al. (2008)	AHP	Deficiencies in the operation of the logistics system	Weight scoring method is used to select critical criteria and suppliers
Tafernaberri Franzão, E. (2018)	ANP	Late delivery of contracted products or services	The article has proposed a multi-perspective approach framework for provider selection
Yadav. V & Sharma. M (2015)	AHP	Product delivery defective and/or incomplete or inadequate services	The proposed model can handle many suppliers. Furthermore, it does not require any special programming or complex computational efforts
Perçin, S. (2006)	AHP, LP	Deficiencies in the supply of raw materials and inputs for production	To consider quantitative and qualitative factors in selecting the best suppliers and assigning optimal order quantities among them
Kar, A (2015)	AHP, FUZZY, ANN	Loss of customers by not following up on claims	To determine the optimal order of quantities to be allocated to multiple suppliers under consideration of additional restrictions. Models can be used to automate workflow, to maintain supplier records, and to standardize evaluation and order allocation processes

4 Discussion

Procurement management to be considered a true source of competitive advantage within the supply chain requires more efficient logistics processes. Its strategy should be aligned with the business strategy and with the overall objectives of competitiveness; therefore, procurement targets should be set based on a set of criteria, such as cost, quality, delivery time, service, among others. In many cases these criteria make the selection of supplier's complex, because most cases these criteria are of an eminent nature. Because the supplier's selection of in business management is so important, it is essential to find ways to try to eliminate subjectivity in the supplier selection process using specific tools. To achieve this, it is important to have a well-defined process or methodology that allows us to select the best supplier.

According to the different examples presented above, this article proposes a methodology for supplier selection with which we could appropriately select suppliers. The proposed methodology has four steps and its represented in the Fig. 1:

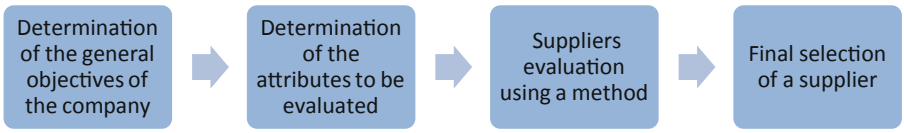

Fig. 1. Representation of the methodology

1. Determination of the general objectives of the company: At this stage you must carry out a trace of all those suppliers that can or present influence in the market that is located the company and for this purpose the managers of the purchasing department and the general management of the company must perform a series of questions and their respective analyses that will lead to greater clarity of the problem.
2. Determination of the attributes to be evaluated: These criteria or attributes must be chosen by the decision group or group of choice of the company. As well as through direct observations to the process consult the criteria that are used in the literature, which have already been analyzed in previous chapters. each company is a special case that presents its own needs and that can face different problems, the criteria must be selected according to these problems.
3. Evaluation of suppliers using a method: Once the selection criteria are defined, the next step is to select suppliers by applying a certain method. The selection method must be consistent with the analysis of the context, the realities of the supply chain and the selected criteria. As shown in the previous chapter, you can use an individual method or built-in methods, it all depends on what you want to get.
4. Final selection of a supplier: At this stage it is advisable that the decision group that has made the selection process, inform the senior management or senior managers of the company, in relation to the supplier that has been chosen, since it is they who must observe the attachment that this may have with the objectives and strategic plans that the company has.

5 Preliminary Results

The application of the proposed methodology will be carried out in the process of purchasing the Resin as one of the main raw materials used in the production of plastic products in a company that supplies these products to the automotive industry.

5.1 Determination of the General Objectives of the Company and Determination of the Attributes to Be Evaluated

The problem in this case study lies in the need to select the appropriate suppliers that can improve the performance of the procurement process of that company, cause the automotive sector is a very demanding one that requires there are not had any delays or product quality deficiencies because it can lead to very serious penalties.

To determine the critical indicators for the problem that concerns us and as part of the second step of the methodology, the Delphi Method was applied. This tool aims to obtain the most reliable consensus of opinions from a group of experts regarding a specific topic [37]. For the application of this method, the main opinions of the literature regarding the main attributes, criterias or indicators for the selection of suppliers in the automotive sector are taken.

From the research carried out, 45 criteria or fundamental indicators were obtained. For which a qualification of each one of the authors is provided according to exposed in their articles, using the scale with scores between 1 and 5. The results of the application of the method are shown in the tables where E1, E2, E3, E4, E5, E6, E7, E8, E9 and E10 represent the experts.

After analyzing the results of the application of the Delphi Method and using the Pareto Principle or also known as the 80/20 Rule, which establishes that the 80% of the consequences are derived from 20% of the causes; it can say that of the 45 criteria or indicators mentioned by the experts, the most important or critical criteria that represent approximately 20% of the total score are the following, in order of importance according to the percent they represent:

- Adequate quality of the supplies,
- certified Quality Management Systems,
- Adequate sale price,
- Minimum delivery times,
- Technological Capacity.

On the other hand, to check if there is agreement between the judgments of the experts regarding their selection in order to continue with the research, we will use a statistical tool called Kendall's Concordance Coefficient (W) (Table 3).

Kendall's coefficient of concordance (W) measures the degree of agreement between a group of elements (K) and a group of characteristics (n). It is commonly used in attribute agreement analysis. Kendall's coefficient values can range from 0 to 1. [38]. This statistician follows a Chi-square Distribution. For the development of this test two hypotheses are used:

Table 3. Result of the application of the Delphi Method

Delphi method											
Criterias	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	%
Quality of the supplies	5	5	5	5	5	5	5	5	5	5	0.0544
Certified quality management systems	5	4	5	4	4	5	4	4	4	4	0.0468
Sale price	4	4	5	3	5	5	4	5	1	5	0.0446
Minimum delivery times	4	4	5	4	4	1	1	5	5	5	0.0413
Technological capacity	1	5	5	3	5	5	4	4	5	1	0,0413
Total											0,2285

- Null hypothesis or H0: There is no agreement among the experts. $W = 0$ $p > \alpha$
- Alternative hypothesis or H1: There is agreement among the experts. $W > 0$ $p < \alpha$.

The Table 4 shows the value of the coefficient W with a significance level $\alpha = 0.05$ and $n = 5$ and degrees of freedom.

Table 4. Kendall's coefficient of concordance (W)

Kendal's coefficient			
W	Chi-square	DF	P
0,311940	12,4776	4	0,0141

Given that $W = 0.31194 > 0$ and $p = 0.0141 < 0.05$, H0 is rejected and H1 is accepted, therefore we can conclude that there is agreement between the experts. We will use the criterias: quality of the supplies, quality management systems, adequate sale price, minimum delivery times and technological capacity for the next steps of the proposed methodology.

5.2 Evaluation of Suppliers Using an Integrated Quantitative Method

After obtaining the criteria or indicators to evaluate, it proceeds to develop quantitative methods to select the appropriate supplier. For this case study, the managers and the Head of Purchasing have selected 5 suppliers, who have supplied the resin in the last year, a prior evaluation has been carried out on each supplier through a market investigation.

Analytic Hierarchy Process (AHP) Application

Firstly, for the supplier's evaluation, the Analytical Hierarchy Process or AHP will be developed. As previously mentioned, the AHP helps to make decisions in a more rational and understandable way. The AHP methodology for the development of this case is represented in Fig. 2.

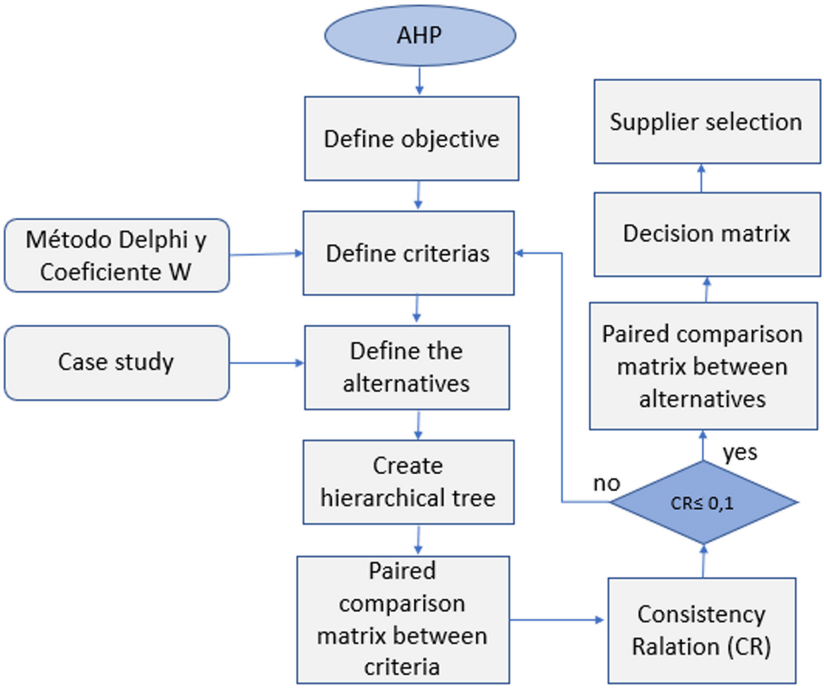

Fig. 2. AHP methodology

The inputs can be actual measurements, but also subjective opinions. Priorities or weightings and a consistency relationship will be calculated [21]. For the application of this method, the 5 criteria that were selected when applying the Delphi Method and the Kendall's Coefficient of Concordance and 5 alternatives or suppliers (S1, S2, S3, S4, S5).

As a first step in the application of the APH method, the paired comparison matrix should be made between the selected criteria A = [aij], where $1 \leq i, j \leq n$, for this, the experts or judges assign weights for each criterion with respect to the others using the Saaty Scale (1–9) (Table 5).

Table 5. Escala de Saaty

Intensity of importance aij	Definition	Explanation
1	Equal importance between i and j	The two criteria contribute the same to the objective
3	Little importance of element i over element j	Experience and judgment slightly favor one criterion over the other
5	Strong importance of element i over element j	Experience and judgment strongly favor one criterion over the other
7	Much stronger the importance of element i over element j	One criterion is favored very strongly over the other. In practice you can demonstrate your mastery
9	Absolute importance of element i over element j	The evidence favors one factor over the other to the highest degree

The paired comparison matrix between the selected criteria is shown in Table 6.

Table 6. Paired comparison matrix between criterias

Paired comparison matrix											
	C1	C2	C3	C4	C5	Normalized matrix					Average vector
C1	1	5	5	1	5	0,38	0,66	0,41	0,29	0,24	0,40
C2	1/5	1	3	1	5	0,08	0,13	0,24	0,29	0,24	0,20
C3	1/5	1/3	1	1/3	3	0,08	0,04	0,08	0,10	0,14	0,09
C4	1	1	3	1	7	0,38	0,13	0,24	0,29	0,33	0,28
C5	1/5	1/5	1/3	1/7	1	0,08	0,03	0,03	0,04	0,05	0,04
SUM	2,60	7,53	12,33	3,48	21,00						

Subsequently, the alternatives are compared, that is, the 5 providers with respect to each of the 5 criteria. Therefore, comparison matrices of the alternatives are built according to each criterion and the proper or average vectors of each matrix are calculated (Table 7)

As our objective is to make a decision based on the 5 criteria and their importance, we proceed to multiply the matrices, one of them is composed of each of the weights of

Table 7. Average vectors of each supplier with respect to each criteria

	C1	C2	C3	C4	C5
S1	0,45	0,26	0,15	0,24	0,11
S2	0,15	0,22	0,11	0,17	0,22
S3	0,16	0,09	0,40	0,18	0,26
S4	0,07	0,09	0,10	0,19	0,12
S5	0,17	0,34	0,23	0,22	0,29

the alternatives based on each of the criteria and the other is the weighting of the criteria.

$$\begin{bmatrix} 0,45\ 0,26\ 0,15\ 0,24\ 0,11 \\ 0,15\ 0,22\ 0,11\ 0,17\ 0,22 \\ 0,16\ 0,09\ 0,40\ 0,18\ 0,26 \\ 0,07\ 0,09\ 0,10\ 0,19\ 0,12 \\ 0,17\ 0,34\ 0,23\ 0,22\ 0,29 \end{bmatrix} \times \begin{bmatrix} 0,40 \\ 0,20 \\ 0,09 \\ 0,28 \\ 0,04 \end{bmatrix} = \begin{bmatrix} 0,31 \\ 0,17 \\ 0,18 \\ 0,11 \\ 0,23 \end{bmatrix}$$

The final average vector indicates the weight of each alternative and therefore allows us to choose the best option. Based on the 5 criteria and their importance, the best alternative is Supplier 1 because it has the highest weight (0.31) followed by Supplier 5 (0.23), Supplier 3 (0.18), Supplier 2 (0.17) and finally the Supplier 4 (0.11).

Several analyzes can be carried out based on this result, from the need to make a systematic evaluation of the providers based on the criteria that were selected. Encourage and work together with the supplier 5 so that it can improve its performance in terms of a certified quality management system and that it complies to a greater extent with the quality specifications that are requested (since these are the highest criteria weight for decision makers in the company). To complement our decision, a model of artificial neural networks will be applied.

Artificial Neural Networks (ANN) Application

In this particular case study, another important element for which this neural network tool will be used is that our research is developed in the automotive industry and this industry is currently very demanding in terms of delivery, quality, logistics performance, provisioning, etc. As previously mentioned, artificial neural networks are used for prediction tasks and lead to an intelligent system that can successfully perform complex tasks. They can create patterns, recognize information, or solve complex problems.

The methodology to be followed for the development of neural networks in our case study is represented in the Fig. 3

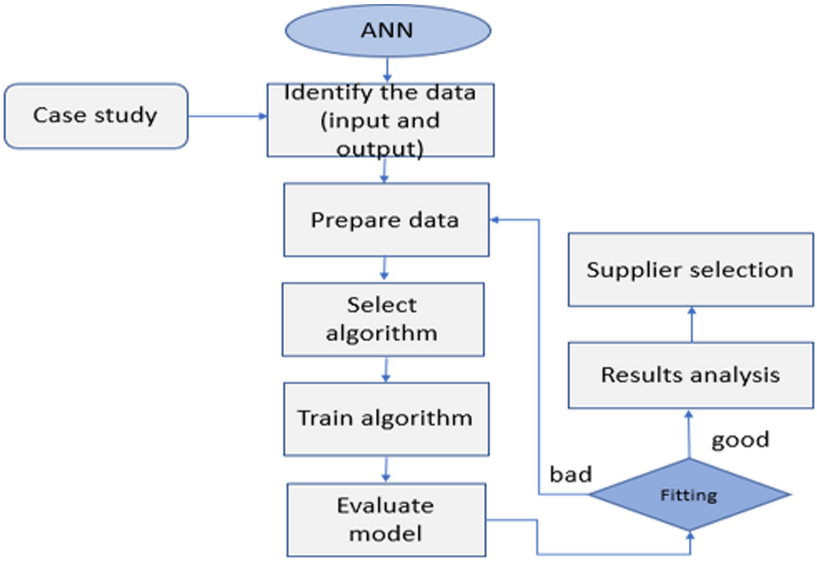

Fig. 3. ANN methodology

There are four aspects that characterize a neural network: its topology, type of association between the input and output information, the learning mechanism, and the form of representation of this information.

Particularly for our case study, which is a classification problem where there is input and output information, it will use the Feedforward Backpropagation network type, because a supervised learning mechanism is needed and this type of network is the most recommended for this kind of problems. Backpropagation networks have demonstrated their ability to work successfully in a wide range of applications including classification.

Particularly in our case study, the input data correspond to the evaluation of 5 suppliers for each of the 5 criteria in specifically 8 different stages that are the representative scenarios of our problem (40 suppliers) for a total of 200 input data, with a scale of 1–5 as follows, by the coordinating group of the company where the investigation was carried out:

1. Not at all satisfied with the supplier's performance
2. Not very satisfied with the supplier's performance
3. Neutral
4. Very satisfied with the supplier's performance
5. Totally satisfied with the supplier's performance (Table 8).

Table 8. Input data

	St1	St2	St3	St4	St5	St6	St7	St8
S1	5	5	3	4	5	2	3	5
S2	3	4	3	4	5	2	2	3
S3	4	1	2	3	5	2	4	2
S4	1	1	2	1	5	4	4	1
S5	1	1	1	1	3	5	4	4
S1	3	1	1	1	2	4	5	4
S2	3	3	4	5	1	3	5	4
S3	3	2	4	5	1	3	1	5
S4	4	4	4	5	5	5	1	2
S5	2	5	5	5	4	5	5	1
S1	1	1	1	4	4	4	5	3
S2	3	2	1	2	1	2	2	5
S3	3	4	1	2	2	1	3	5
S4	1	4	2	1	2	1	4	5
S5	2	5	3	2	3	1	4	4
S1	3	5	4	3	4	3	5	1
S2	2	5	4	3	5	3	5	2
S3	2	2	4	3	1	5	3	4
S4	2	1	5	1	1	5	4	5
S5	1	1	1	5	2	4	1	1
S1	3	2	2	5	4	2	2	5
S2	1	3	4	5	5	1	5	3
S3	2	4	5	5	3	1	5	2
S4	3	4	2	2	1	1	5	1
S5	5	5	2	2	1	5	5	5

The output data will correspond to the result of the application of the AHP for the 5 alternatives with respect to the 5 criteria, in the same stages (Table 9).

Table 9. Output data

AHP	S1	S2	S3	S4	S5	S6	S7	S8
S1	0,305	0,269	0,294	0,185	0,215	0,249	0,182	0,192
S2	0,168	0,217	0,183	0,189	0,175	0,144	0,182	0,187
S3	0,170	0,205	0,190	0,216	0,185	0,232	0,237	0,259
S4	0,120	0,121	0,163	0,237	0,255	0,197	0,233	0,190
S5	0,237	0,188	0,169	0,173	0,170	0,178	0,165	0,172

Another fundamental aspect are the network learning and training. Learning is the process by which a neural network modifies its weights in response to input information. The changes that occur during the learning stage are reduced to the destruction, modification and creation of connections between neurons.

For our training was used the Levenberg-Marquardt training function. This algorithm was developed in the early 1960s to solve online least squares problems. Least squares problems arise in the context of fitting a parameterized function to a set of measured data points by minimizing the sum of squares of the errors between the data points and the function n. The Levenberg-Marquardt algorithm combines two minimization methods: Gradient descent and the Gauss-Newton [39].

Two layers were also used to train our network, one of them hidden with 10 neurons in the hidden layer. As a performance function, the Mean Squared Error was used, and the Sigmoidal Function was used as the propagation function.

The software used for the training and simulation of the neural network was Matlab R2015a. After entering all the information mentioned above in the nntool tool of Matlab, we proceed to train the network, obtaining as a prototype of the neural network the one shown in Fig. 4.

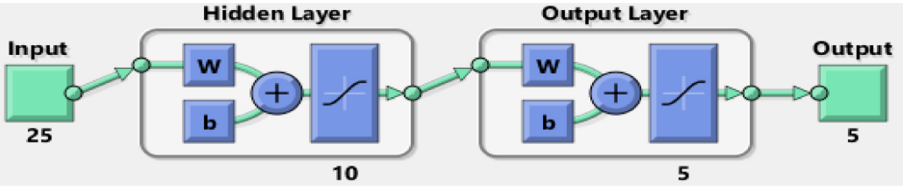

Fig. 4. Neural network's prototype

There are two fundamental aspects that the measurement gives us if the network is correctly trained or not. One of these is the Regression value (R), this value for both training, testing, validation and in general must be very close to 1, the closer to 1 that value is because the network will be better trained o in other terms good fitting. The resulting value of the regression is shown in Fig. 5 where it show that the value $R = 0.99463$, so that means that the network is good fitting.

Another aspect to consider is the accumulated error, in this case the algorithm must adjust the parameters of the network to minimize the mean square error. In this case the accumulated error was $1.25\ e^{-9}$ which represents a minimal error.

After the network is properly trained, it is simulated by entering the data that will be used for this purpose. In this case, 25 data were entered representing the evaluation of the five suppliers (analyzed for the AHP application) for each of the five criterias.

With all this information it proceeds to simulate the network. The output of the network corresponds to the weighting for each of the 5 suppliers (Table 10).

Through the network output, it shows that the supplier with the highest score is Supplier 1 (0.24305), so it is the selected provider. It is important to note that the output of the neural network corresponds to the result derived from the application of the AHP. For that reason, it means that the application of neural networks gives us more reliability to the result that it can obtain from the application of the AHP.

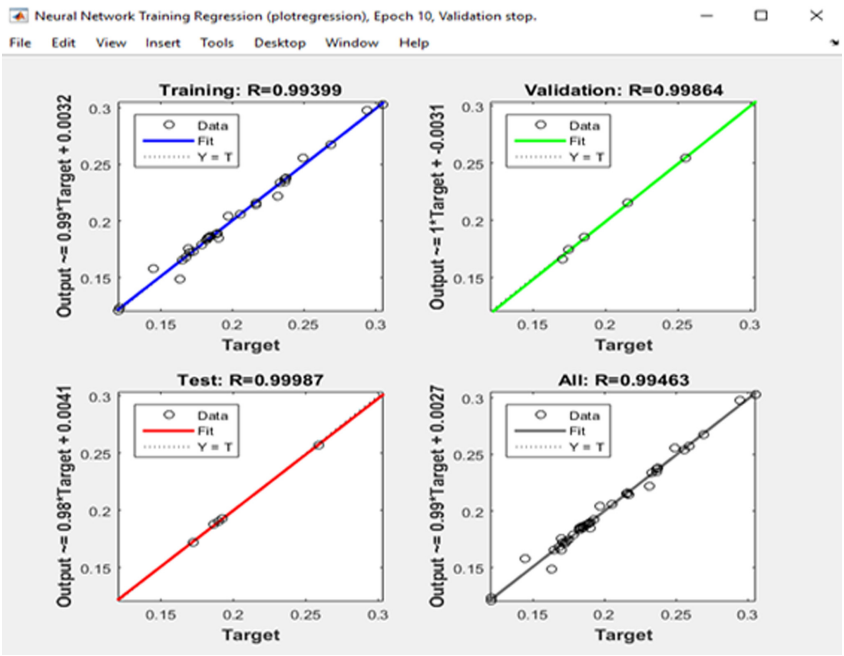

Fig. 5. Regression results

Table 10. Neural Network outputs

Suppliers	Weighting
1	0.24305
2	0.1673
3	0.171
4	0.12055
5	0.2311

5.3 Final Selection of a Supplier

Once the group of providers has been evaluated using the integrated AHP-ANN method, the next activity to perform is the final selection of the provider. At this stage it is convenient for the decision-making group that has carried out the selection process to inform the senior management or senior executives of the company, in relation to the supplier that has been chosen, since they are the ones who must observe the attachment that could have it with the objectives and strategic plans that the company has. It is possible that a decision made from an analytical point of view and based on a decision technique such as the previous ones, will be eliminated because it does not align with the strategic practices and plans of the company.

For this case the Supplier 1 complies in this aspect, which is why it was finally the selected supplier for providing the resin in the agreed period.

6 Conclusions

This study presents a procedure to analyze and select suppliers from an exhaustive search and the analysis of the academic literature related to methodologies or processes to properly select suppliers, selection criteria and even some of the quantitative methods that have been used. This article contributes to the supplier selection process and highlights the importance of supplier selection to improve the performance of the supply chain.

As part of the methodology, it can be concluded that the method choice phase is often the most visible phase of the process, however, the quality of this phase largely depends on the quality of the steps prior to that phase (Determination of the objectives of the company and determination of the attributes or criteria to evaluate). If buyers or decision makers strive to make sound decisions, they should also pay close attention to these first steps.

Also, our analysis showed that there are several criteria for selecting providers which can be objective or subjective. These criteria must be selected according to the environment and objectives of the company, in addition to the strategy that it has designed.

In addition, several of the methods that have been applied and that are useful for dealing with this problem were analyzed in this investigation. The allocation of methods must also be independent for each situation, since they all have different specific characteristics and purposes. The application of the correct method depends largely on the quality of the supplier selection process.

The proposed methodology was applied in a case study with the objective of selecting the appropriate supplier to supply resin for a company within the automotive sector. As important data, an integrated AHP-ANN method was used as a quantitative method to select the supplier, concluding that if a supplier can be obtained objectively, according to the needs of the company using said method.

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