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# An adapted analytic hierarchy process for the supplier selection: Model validation for a textile industry application

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**Abstract**. Nowadays, it becomes increasingly important to efficiently manage business resources so that companies become more competitive in the market. Bearing in mind the current crisis (e.g., lack of components, economic constraints), it has become increasingly difficult to make a cautious selection of suppliers for the industrial context. The paradigm for suppliers' selection and evaluation has been changing and may include different criteria, which is difficult to compare without a decision support system. Price is no longer the companies' exclusive main concern given the difficulty in accessing raw materials or components. Environmental sustainability criteria have been introduced as a relevant factor to consider when choosing a new supplier. The delivery time, the quality of the materials, the flexibility, the capacity of response and the costs associated with the logistics have become criteria with greater weight in the final decision. Faced with this diversity of criteria, companies increasingly need to have systems that can help in their decision-making process. In this work, it is proposed an adapted analytic hierarchy process model for supplier selection, applied in a textile company. According to the diversity of criteria, a multi-criteria decision support model was implemented that considers both quantitative and qualitative criteria. The model is adapted from an analytic hierarchy process and assigns a weighting to each supplier, considering the different criteria. This algorithm was developed in Python. The final output is made available through a ranking system. At the end of the process, the decision maker can select the most promising supplier (supplier A with a weight of 29.3%) for the defined criteria, allowing a more informed decision by the company.

**Keywords**: Supplier selection, Multicriteria decision; Decision support model; Analytic hierarchy process.

## 1. Introduction

Companies with an efficient management of resources may become more competitive in an increasingly demanding market. The recent crisis with respect to the lack of material has highlighted the need for a more careful selection of suppliers for companies. Due to the existence of a large number of available criteria when selecting and evaluating suppliers, it becomes difficult to make a careful comparison without a decision support system. Due to the increasing difficulties in accessing certain raw materials, the cost criterion may not be an exclusive criterion for the company. For example, criteria related to sustainability, product quality, delivery time, flexibility and responsiveness have become increasingly valued by the companies' decision-makers. Although sustainability-related criteria are more present at the time of the decision, in some companies, these should have a higher weight at the time of the final decision. For a better management of the criteria and their weighting, there are several models that can be applied to help in the decision-making process, such as Multi-Criteria Decision-Making models (MCDM). In 2021, Azhar et al. [1] analyzed the application of different MCDM while identifying their main scenarios of utilization. The authors categorized such MCDM techniques according to the used approach, namely pairwise comparison, outranking or distance based. Some explored models were the Analytic Hierarchy Process (AHP), the Analytical Network Process (ANP), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), among others. The selection of a MCDM technique must consider its application scenario and the corresponding specificities. The AHP method has been used in several industries with the goal of selecting the best supplier. Indeed, in [2] this approach was used in a coffee-roasting plant to determine a new supplier based on different criteria such as price and taste. Another example is presented in [3] where the fuzzy AHP was used to define the supplier for a hand tractor assembly process. Menon and Ravi [4] applied a combined MCDM methodology, AHP and TOPSIS, for the selection of suppliers in an electronic supply chain. In [5] and [6], AHP was applied with the goal of selecting the most suitable supplier in the glove industry, and an iron and steel plant, respectively. For the selected case study the AHP technique was selected since it is particularly used when there is incomplete information or there is an inherent subjectivity of the decision agent [7].

## 2. Adapted Analytic Hierarchy Process

The AHP is a method that is used to support the decision-making process when it is complex. Indeed, the AHP may simultaneously deal with several criteria and subjective considerations by decision-makers. The AHP model implemented in this paper is summarized through the flowchart presented in Figure 1.

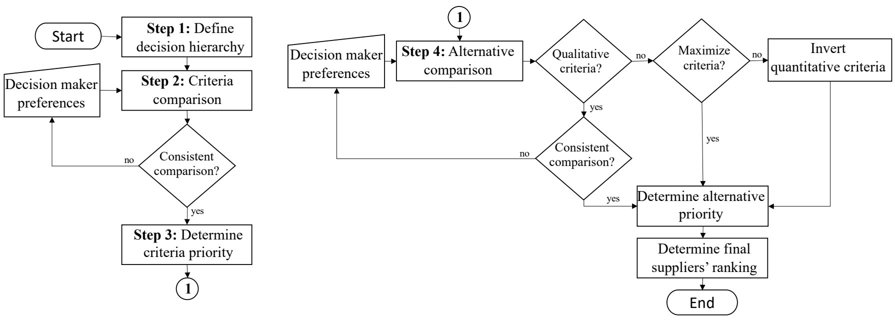



*Figure 1. Adapted Analytic Hierarchy Flowchart*

In a first phase, it is necessary to define the decision hierarchy (Step 1). For the three-level model, the first level represents the objective of the problem, the second identifies the criteria and the third the alternatives. Subsequently (Step 2), and based on the preferences of the decision maker, a criteria comparison matrix is created. If this matrix is consistent, *i.e.*, it has coherence from a mathematical point of view, a vector is calculated which represents the relative priorities associated with each criterion (Step 3). Once this vector is normalized, the sum of the priorities must be equal to 1. When the matrix is not consistent, it is necessary to request its revision to the decision agent. In step 4 the alternatives are pairwise compared for each of the criteria. If the criteria are qualitative, then this process is analogous to that referred to in step 2. For each criterion a vector of relative priorities is created. In case of quantitative criterion, if the objective is to minimize, its value is inverted, *i.e*., the value one is divided by its original value and later the vector is normalized (sum of the values equal to 1). If the objective is maximization, the normalized vector is directly created. The product between the priority vector of the criteria and the matrix of priorities of the alternatives (one vector for each column) originates the final classification of the alternatives. The highest value corresponds to the best alternative. The presented model is adapted from the original model since it simultaneously considers quantitative and qualitative criteria with different optimization objectives.

## 3. Case Study Description

With the aim to analyze the behavior of the proposed adapted AHP model in the supplier selection and evaluation problem, a case study in an industrial context was defined. This case study was obtained through a real scenario of a company that operates in the textile area, more specifically in textile dyeing. The dyeing procedure is a chemical process where a change in the color of the textile fiber occurs through the application of textile-colored pigments. One of the products that the company frequently uses, and was selected for this study, is a fiber-reactive dye, which is commonly used in the dyeing of cotton or linen. For this product, the company has four specific suppliers that, for confidentiality reasons, will be identified throughout the work as supplier A, B, C and D. To analyze which is the most suitable supplier to provide the pigment, five specific criteria were used. These criteria are identified and defined by the company's decision maker as presented in Table 1. The main selection criteria used are cost (in monetary units), product quality, history/relationship with the customer (in years), delivery time (days) and the sustainability conditions under which the pigment is produced. The criteria can be qualitative, where the decision-maker must identify the preference level for the supplier considering that criterion, e.g., the decision-maker may prefer supplier A in detriment of D with respect to the quality criterion. The criteria can also be quantitative when it is possible to define a minimization or maximization objective before a numerical value is set. For example, a lower value price should be preferred over a higher value price if the objective is to find a product with a competitive price. These values are previously known by the decision-making agent and do not require subjectivity, since they are represented by known numerical values.

*Table 1. Criteria to select best supplier for textile pigment.*

| Criteria | Type | Objective | Definition |
|---|---|---|---|
| Cost | Quantitative | Minimization | Represents the unit cost, the amount that the company will pay when purchasing a unit of pigment. This value already includes all the costs to acquire the product, including its transportation value. |
| Quality | Qualitative | Preference level | Refers to the quality of the product that was delivered by the supplier. This classification depends on several aspects that determine whether the product conforms and meets the requirements of the company and the customer. |
| Delivery time | Quantitative | Minimization | The deadline is considered as the delivery period, from the moment the company orders the pigment from an external supplier until it arrives at the intended location. |
| History | Quantitative | Maximization | The history of partnering with a supplier can be used to assess reliability and consistency over time. If a supplier has a long history of partnering with the company, it could indicate that it is reliable and may offer quality products. The partnership history refers to the number of years the company has been in partnership with a given supplier. |
| Sustainability | Qualitative | Preference level | Foresees the classification of suppliers with sustainable practices and techniques in the development of the pigment. These sustainability measures include a set of good practices such as making packaging more sustainable and environmentally friendly, dealing with renewable energy sources, choosing recyclable materials, among others. |

With this case study, the aim is to select the most suitable supplier to provide the company with the referred pigment, considering all the presented criteria.

## 4. Model implementation and validation

In this section, the modified AHP model is presented and discussed, being applied to the previously mentioned case study. For a clearer presentation of the results, this method will be divided into different steps. The adapted AHP model was implemented in Python programming language. Throughout the various steps, intermediate results will be presented using the mathematical language and intermediate outputs requested from the Python programming language in order to validate such intermediate results.

### 4.1. Decision hierarchy (Step 1)

In this step, the original problem is divided into smaller subproblems. Thus, it is possible to analyze the sub-problems with a more specific detail. With this structure, one is able to analyze how the results of lower levels of the hierarchy can influence other levels of higher order. The upper hierarchical level represents the global objective and is represented through a single element that, in this case, represents the selection of the most suitable supplier to provide the company with the referred pigment. Each of the following levels can contain several elements. However, in order to make a fair comparison between the various elements and levels, a common unit of measurement must be used, *i.e.*, a weighting factor. As shown in Figure 2 this problem has three levels of hierarchy.

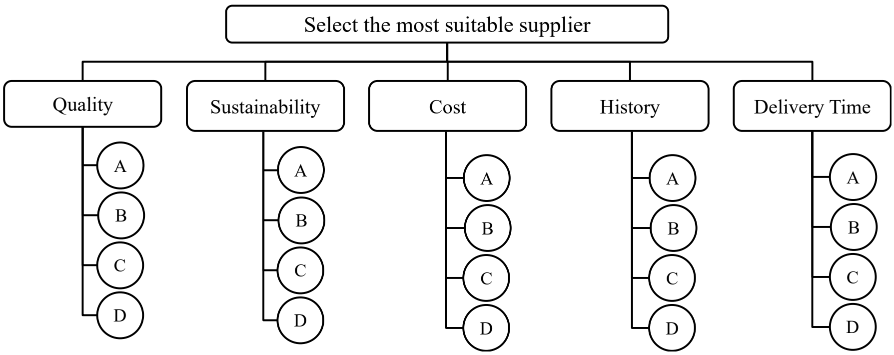



*Figure 2. Structure for the adapted AHP*

The first level presents the global objective of the problem. At the second level, five different criteria are considered, namely, cost, product quality, history, delivery time and sustainability. The third level is represented by the different alternatives that are associated with each of the presented criteria, in this case, supplier A, B, C and D (for confidentiality reasons the identification of the four suppliers is undisclosed).

## 4.2. Criteria pairwise comparation (Step 2)

To make a fair comparison between criteria and understand which criteria are most valued by the company, the decision-maker assigned a preference level between the different criteria. With this attribution, it was possible to create a criteria comparison matrix. These preferences are quantified on Saaty's fundamental scale, which uses a scale between 1 and 9 [8] to establish a qualitative relationship between criteria. The first level of the scale (1) identifies equal importance between criteria, level 3 denotes a weak importance of one over the other. This importance grows up to level 9, where there is a greater degree of security to favor one criterion in detriment of another (highlighted with an intensity color scale axis). The comparison matrix established by the decision-making agent can be seen in Figure 3. In this figure, it is possible to verify that the decision-making agent considers that the cost is a little more important than the quality of a product (value 3 on the fundamental scale of Saaty). The opposite must also be verified, *i.e.*, quality is slightly less important than cost (1/3) which corresponds to the value 0.333 rounded to three decimal places.

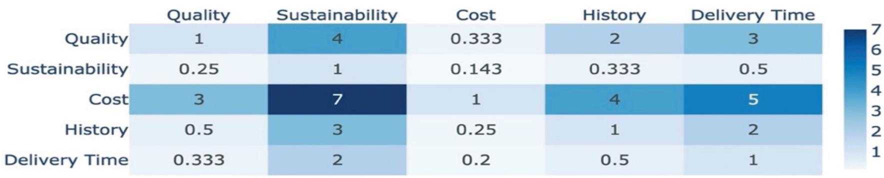



*Figure 3. Criteria pairwise comparation matrix*

Analyzing the comparison matrix, it is possible to verify that the most important criterion for the company is the cost, despite the current change in industrial paradigm. Yet, quality is the second-ranked criterion. The sustainability criterion is still a factor that is not highly valued by the company.

## 4.3. Relative priority of each criterion (Step 3)

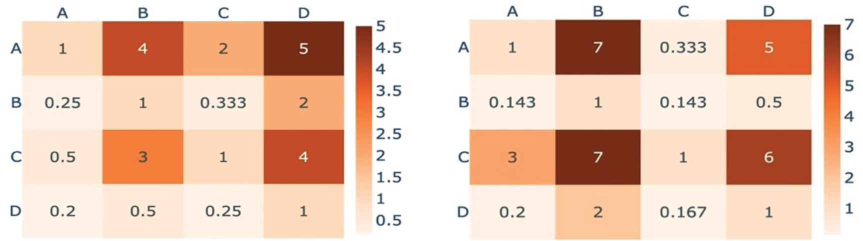
Based on the criteria comparison matrix, it is possible to calculate the relative weights (priorities) associated with each criterion. In terms of Linear Algebra, this procedure corresponds to the calculation of the eigenvector with the highest eigenvalue and its normalization (vector with values between 0 and 1). The eigenvector can be approximated by dividing (element by element) the column associated with each criterion by the sum of the value of the respective column. This approximation proved to be of good quality and more efficient in terms of computational performance. Finally, the arithmetic mean is calculated for each line of the normalized correlation matrix, obtaining the priority vector for the different criteria. The numerical values of the obtained vector correspond to the total normalized weight assigned by the decision agent to each criterion (Figure 4).


*Figure 4. Criteria relative priority*

It is possible to observe that cost is the criterion with the greatest impact on weighting (49.3%), followed by quality with 22.4% and history (14.1%). Delivery time and sustainability have a smaller impact, having a weighting of 8.8% and 5.4%, respectively. These weightings seem to be consistent with the decision-making agent's indications. However, it is necessary to check the consistency in a systematic mathematical way as demonstrated by Saaty in [8]. In this case, the consistency ratio is 0.0174. As this value is less than 0.1, it is possible to assume the consistency of the matrix. If the matrix was not consistent, it is possible to try to make it consistent with mathematical methods, or the decision-maker would need to reformulate the comparison matrix.

### 4.4. Alternative comparation (Step 4)

In this phase, the alternatives are compared according to each of the criteria. In this version of the AHP model it is possible to use qualitative and quantitative criteria. For each of the qualitative criteria a comparison matrix is created (analogous to step 3). This information is shown in Figure 5, where it can be observed that for the quality (Figure 5 a.) and sustainability criteria (Figure 5 b.) supplier A and C are the ones with the higher values, with intensity higher than 1. Both matrices have adequate consistency ratio, 0.0180 and 0.0584, respectively. Regarding quality, the decision-making agent considers that supplier A is slightly better than supplier C. In terms of sustainability, supplier C is slightly better than supplier A.




*a)* *b)*

*Figure 5. Qualitative alternative pairwise comparation matrices: a) quality; b) sustainability.*

In the quantitative criteria, the real values associated with the criterion are used to create the weighting vector for the different alternatives. However, it is necessary to define the company's objective in relation to each criterion (Figure 6). For example, the decision-maker indicated that the company values more suppliers with shorter delivery times. Therefore, it is necessary to calculate the inverse of this value in the weighting and normalization of the priority vector, so that the supplier with the shortest delivery time has a greater weighting in the model.


*a)* *b)* *c)*

*Figure 6. Quantitative alternative comparation by criterion: a) cost; b) history; c) delivery time.*

The most suitable supplier in satisfying the company's needs, according to the comparison criteria defined by the decision agent, is selected through a ranking system. For this, it is necessary to calculate the vector of the composed priorities of the alternatives, considering all the criteria. This is obtained by multiplying the matrix containing the priority vectors of each criterion for the different alternatives (third level of the hierarchy) by the priority vector associated with the different criteria (second level of the hierarchy). The result of this calculation can be seen in Figure 7, which presents the vector of composite priorities ordered from the most to the least suitable supplier.

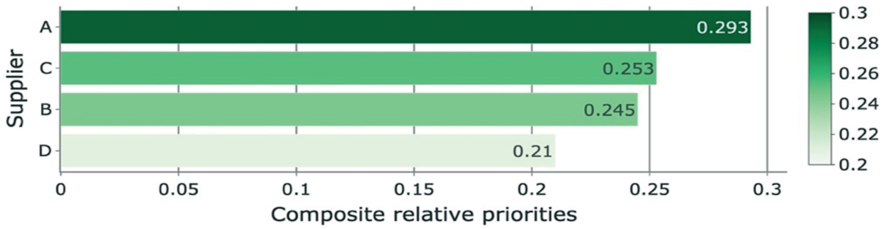
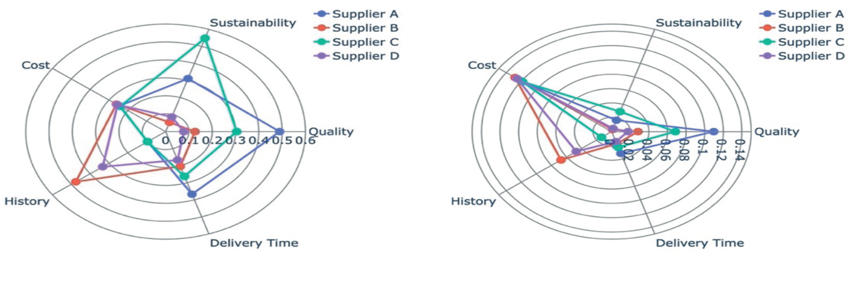



*Figure 7. Final supplier's ranking*

Supplier A obtained a priority of 0.293, then supplier C with a slightly lower priority (0.253), supplier B with 0.245 and supplier D with a lower priority (0.210). This analysis leads to the conclusion that supplier A, according to the established criteria, is the most suitable supplier to meet the company's needs.

## 5. Critical analysis of the results

To understand how the criteria impacted the selection of supplier A, a critical analysis of the results will be made. It is important to emphasize that the adapted AHP helps in decision support, creating more informed decisions within the company. However, it is necessary to contextualize the period in which the decision was taken, as this can have a great influence on the final decision. In this case study, the company had a low demand for the pigment, which made it possible to value the cost criterion to the detriment of others, such as delivery time. According to the decision-maker, the quality criterion is not influenced by demand since the quality requirements do not change with demand variations. Figure 8 highlights the main differences between the behavior of the weightings of the alternatives, without and with the weighting of the criteria, attributed by the decision-maker.




*a)* *b)*

*Figure 8. Final supplier's ranking comparation: a) Without criteria weighting, b) With criteria weighting.*

In general, it is possible to verify that the most important criteria for the decision-maker are enhanced in the vector of composite priorities, that is, in the final decision (Figure 8. a.). For example, supplier C is the one that has the highest weighting in the sustainability criterion, however, as it is a criterion still little valued by the company, it has little relevance in the final decision. The opposite occurs in the cost and quality criteria.

## 6. Conclusions and future work

Efficient resource management makes companies increasingly competitive. To correctly deal with the numerous criteria associated with decision problems, it is essential to use decision support systems. In addition to indicating the most promising solution, they also allow justifying decisions within companies. This paper presents an AHP model for selecting the most suitable supplier in a company that operates in the textile sector and is looking for a supplier for a specific textile pigment. The results show that the cost and quality criterion prevailed in the selection of supplier A, since the decision-making agent leveraged these criteria due to the low demand presented at the time the case study was collected. As future work, it will be necessary to create a software with a user-friendly interface allowing to present the results in real time to the decision-maker. Another factor to consider in the future is the comparison matrices consistency which must be subjected to a mathematical procedure to ensure it, before asking the decision-maker for its adjustment.

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