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# Research and Application of FAHP in Bidding Quotation for Petroleum Geophysical Prospecting Project

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## Abstract

This paper mainly talks about the main layer analytical method, and fuzzy comprehensive evaluation, fuzzy hierarchical analysis (AHP) method of a deeper connotation, and further discusses its application in bidding quotation for petroleum geophysical prospecting project. Fuzzy analytic hierarchy process (FAHP) integrates many merits of AHP and fuzzy comprehensive evaluation organically. It determines the weight of each affecting factor using analytic hierarchy process at first, and then uses the fuzzy comprehensive evaluation method to determine each scheme index. FAHP can effectively enhance the decision-making efficiency.

## Keywords

Fuzzy Comprehensive Evaluation, Fuzzy Matrix, Petroleum Geophysics, Bid Price

## 1. Introduction

Evaluation and decision making is a frequent and important cognitive activity in human society [1]. As a combination of qualitative and quantitative decision-making tools, the analytic hierarchy process has been developed rapidly in recent years, but because of the fuzziness of the complexity of things and people's understanding of objective things, the ordinary AHP has some obvious shortcomings; that is there are significant differences between the consistency of the judgment matrix and human's thinking [2]. As a result, the fuzzy analytic hierarchy process is improved and optimized.
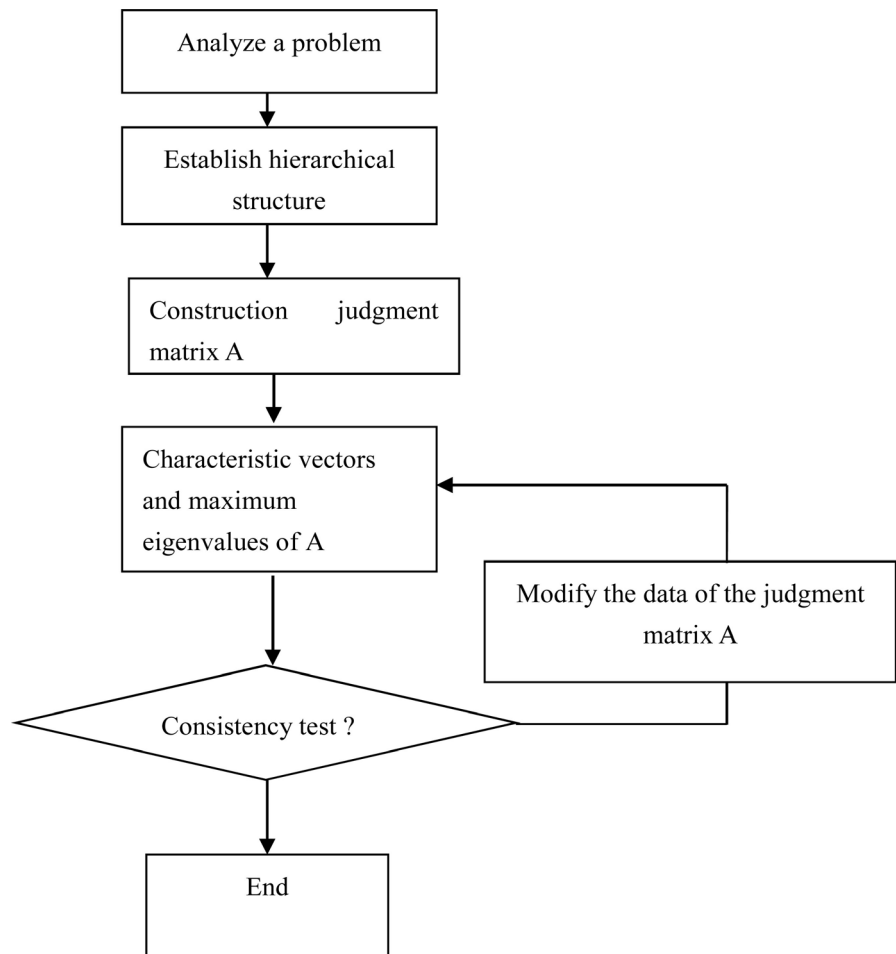
## 2. Research on AHP

### 2.1. Principles of AHP

In 1977, the concept of analytic hierarchy process abbreviated as AHP was first proposed by an American operational research expert T. L. Satty [3]. The general idea of AHP method is decomposing a problem to study, thus the problem is divided into different elements, then we will group and sort each element, and different groups have different levels, so as to form a hierarchical structure. Then we compare the elements at different levels, and judge the importance between each element, and then combine the subjective judgments of people to give the overall importance order of the decision plan.

### 2.2. Model and Procedure of AHP

The AHP model is the foundation of AHP method, and it is also the basic characteristic of AHP. The steps of analyzing a problem and making a decision using the AHP method are shown in Figure 1.

There are six steps to use AHP to make a decision, they are making problem clearly, establishing hierarchy structure, making judgment matrix, single level



**Figure 1.** Flow Chart of AHP.

sorting and consistency checking, overall hierarchical sequencing and make corresponding decision.

## 3. Fuzzy Comprehensive Evaluation Method

### 3.1. The Principle of Fuzzy Comprehensive Evaluation Method

The fuzzy method was founded by an American scientist Professor Called Chad in 1960s [4]. It is a kind of evaluation model and method for a large number of economic phenomena in the real world with the characteristics of fuzzy design. The principle of fuzzy comprehensive evaluation is this: the first step is to determine the analysis index set and evaluation set of problems, and the second step is to construct the fuzzy evaluation matrix on the basis of determining all the factors' membership degree and weight, and the third step is to put the weight vector of each factor and fuzzy evaluation matrix to do fuzzy operation, and then do the normalization processing to get a comprehensive value of fuzzy evaluation.

### 3.2. Model and Procedure of Fuzzy Comprehensive Evaluation Method

Fuzzy comprehensive evaluation method has a good evaluation effect, and it is a good tool especially for complex problems of many factors. Its mathematical model is relatively simple, and it is easy to master. The fuzzy set in the fuzzy comprehensive evaluation method break the rules that membership degree can only be 0 and 1,and extend two valued logic to any infinite values of continuous logic, and it can be fuzzy concept as "both this and that". The modeling steps are as follows: to determine the evaluation factors and the evaluation level, and to construct the judgment matrix and to determine the weights, and to make fuzzy synthesis and to make decisions at last.

## 4. Fuzzy Analytical Hierarchy Process

### 4.1. The Foundation of Fuzzy Analytic Hierarchy Process

Fuzzy analytic hierarchy process (AHP) is based on the following definitions and theorems:

**Definition 1** Let matrix $F = \left(f_{ij}\right)_{n \times n}$, if $0 \leq f_{ij} \leq 1 \left(i, j \in \Omega\right)$, then it is said that $F$ is a fuzzy matrix.

**Definition 2** If the fuzzy matrix $R = \left(r_{ij}\right)_{n \times n}$ meets $r_{ij} + r_{ji} = 1$, then it is said that $R$ is a Fuzzy complementary matrix.

**Definition 3** If the fuzzy matrix $R = \left(r_{ij}\right)_{n \times n}$ meets $r_{ij} = r_{ik} - r_{jk} + 0.5 \left(i, k, j \in \Omega\right)$, then it is said that $R$ is a Fuzzy consistent matrix.

**Theorem 1** The necessary and sufficient condition for the fuzzy matrix R to be a fuzzy consistent matrix is that the difference between the corresponding elements of any two rows in R is constant.

**Theorem 2** The necessary and sufficient condition for the fuzzy matrix R to

be a fuzzy consistent matrix is that the difference between the specified elements of any row and the rest of the rows in R is constant.

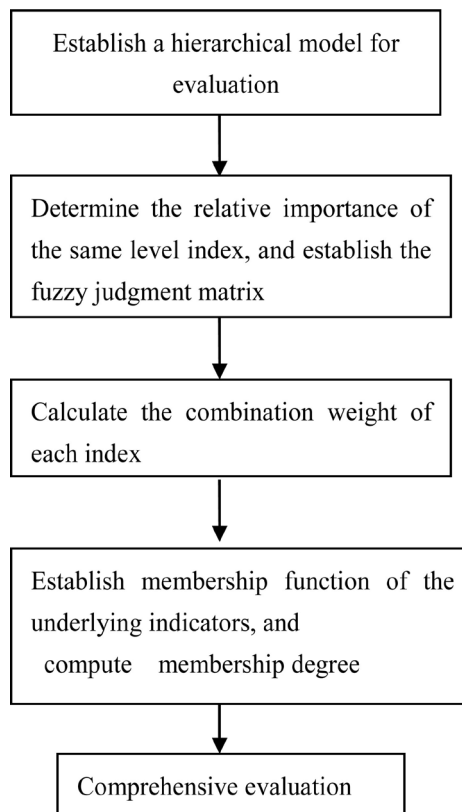**Theorem 3** If R is a fuzzy consistent matrix, its weight can be expressed as formula (1):

$$w_i = \frac{1}{n} - \frac{1}{2a} + \frac{1}{-na}\sum_{k=1}^{n} r_{ik}, i \in \Omega \tag{1}$$

## 4.2. The Solution Process of Fuzzy Analytic Hierarchy Process

The method of FAHP uses priority relation matrix to realize qualitative description and decision thinking into quantitative description decision thinking, and its evaluation flow chart is shown in **Figure 2**.

1) Setting up a hierarchy diagram

In order to organize the problems under study, we need to analyze the subjects accurately and detailedly, and simplify the complex problems, distinguish the levels, and construct the hierarchical structure. The hierarchical structure is generally divided into three layers: the top (the target layer): this level has only one element, and it is ideal for the general problem analysis or the intended target, so it is also called the target layer; the middle layer (*i.e.* criteria): as the target layer under the rule layer factors; the bottom (*i.e.* measure layer or layer scheme): that in order to realize the goals and decisions of various alternative measures, therefore it is also called the project layer or layer measures.



**Figure 2.** Fuzzy hierarchy evaluation procedure.

2) Construction priority relation matrix

We use the form of matrices to illustrate the importance of the same level relative to its upper level element.

Let the matrix be $F = \left( f_{ij} \right)_{m \times m}$, and if the factor $i$ is more important than the factor $j$, we define the weight $f_{ij} = 1.0$.

Similarly, if the factor $i$ and the factor $j$ are equally important, we define the weight $f_{ij} = 0.5$;

If the factor $i$ is less important than the factor $j$, it is to say $j$ is more important, we define its weight $f_{ij} = 0$.

3) Construction fuzzy consistent matrix

After constructing the priority relation matrix, the next step is constructing the fuzzy consensus matrix.

The first thing to do is to sum of each row of the matrix.

$$r_i = \sum_{k=1}^{m} f_k , i = 1, 2, \cdots, m \tag{2}$$

Then do the following mathematical transformation:

$$r_{ij} = \frac{r_i - r_j}{2m} + 0.5 \tag{3}$$

Similar to the priority relation matrix, the fuzzy judgment matrix can be expressed as follows:

$$
\begin{array}{c|cccc}
C & a_1 & a_2 & \cdots & a_n \\
\hline
a_1 & r_{11} & r_{12} & \cdots & r_{1n} \\
a_2 & r_{21} & r_{22} & \cdots & r_{2n} \\
\vdots & \vdots & \vdots & & \\
a_n & r_{n1} & r_{n2} & \cdots & r_{nn}
\end{array}
$$

Elements have the following meaning: "when elements and elements are compared with elements, elements and elements have fuzzy relationships" ... Than ... A much more important degree of membership.

The element $r_{ij}$ has the following meaning: when the element $a_i$ is compared with the element $a_j$ relative to the element $C$, the element $a_i$ and the element $a_j$ has the fuzzy relationship of membership degree that "... much more important than".

In the evaluation process, in order to distinguish different importance of two elements at the same level, we use 0.1 - 0.9 of the 9 scaling value to indicate that, and numbers between this interval means their importance is between the two values. Scale values and their meanings are shown in Table 1.

By the above scale, we can construct a fuzzy judgment matrix, as follows: (Figure 3)

R has the following properties:

a)  $r_{ii} = 0.5, i = 1, 2, \cdots, n;$

b)  $r_{ij} = 1 - r_{ji}, i = 1, 2, \cdots, n;$

c)  $r_{ij} = r_{ik} - r_{jk}, i, j, k = 1, 2, \cdots, n .$

**Table 1.** Scale and meaning of fuzzy judgment matrix.

| Scale | Definition | Instruction |
|---|---|---|
| 0.5 | Equally important | The comparison between two elements is equally important. |
| 0.6 | Slightly important | Compared to two element, one element is slightly important than the other. |
| 0.7 | Obviously important | Compared to two element, one element is obviously important than the other. |
| 0.8 | Much more important | Compared to two element, one element is obviously important than the other. |
| 0.9 | Extremely important | Compared to two element, one element is extremely Important than the other. |
| 0.1, 0.2 0.3, 0.4 | Inverse comparison | If the element $a_i$ is compared with the element $a_j$ and The judgment is $r_{ij}$, then the element $a_j$ is compared with the element $a_i$ and the judgment will be $1 - r_{ij}$. |

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix}$$

**Figure 3.** Fuzzy judgment matrix.

The fuzzy judgment matrix in essence is a reflection of people's thinking and judgment, and it is unavoidable making some mistakes or errors because of the complicated reality, reflecting fuzzy judgment matrix is inconsistent. Therefore, it is necessary to adjust the consistency of this matrix.

At this time, we can adjust the matrix by the necessary and sufficient conditions of the fuzzy consistent matrix. First of all, we can choose relatively certain judgment elements, and we select $r_{11}, r_{12}, \cdots, r_{1n}$ generally; then elements in the first line minus elements in the second line to see if after down with second line elements minus first line corresponding to the elements, see all the different is a constant, if not, the second element is adjusted until it is to be. According to this method, using the third line elements, the fourth line elements ... to subtract the elements of the first row, and eventually element in the line $n$ minus the first row element and get a constant.

4) Weight calculation and hierarchical single order

The goal of this step is to compute the relative importance order of the factors in the hierarchy relative to the previous level based on the judgment matrix. The common methods are root method and sum method.

Here is the formula for the root method, as shown below:

$$W_s = \frac{\left( \prod_{j=1}^{n} a_{ij} \right)^{1/n}}{\sum_{k=1}^{n} \left( \prod_{j=1}^{n} a_{kj} \right)^{1/n}}, \; i = 1, 2, \cdots, n \tag{4}$$

The whole calculation process is as follows: firstly, multiply each row of elements so as to get N vectors; then do the N root of the vector one by one. Finally, the vector is normalized and we get the final weight vector.

Next is the formula for the sum law, as shown below:

$$W_s = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, \quad i = 1, 2, \cdots, n \tag{5}$$

The whole calculation process is as follows: firstly, each element in each column is normalized; then sum element being normalized to get a new vector; finally the vector divided by N and finally get the weight vector.

5) Hierarchical total ordering

It is usually in a top-down sequence using the method FAHP to make a decision analysis. We usually calculate the importance of the factors in one level relative to elements in the upper level, and finally give the bottom element importance relative to the target layer sequence.

Assuming that there are $n_{k-1}$ elements on the $k-1$ layer, then the weight of these $n_{k-1}$ elements relative to the system is a vector. This sort of vector is

$$w^{(k-1)} = \left[ w_1^{(k-1)}, w_2^{(k-1)}, \cdots, w_{n_{k-1}}^{(k-1)} \right]^{\mathrm{T}} \tag{6}$$

Assuming that sort weight vector on the $k$ layer relative to the $j$ element on the $k-1$ layer

$$p_j^{(k)} = \left[ p_{1j}^{(k)}, p_{2j}^{(k)}, \cdots, p_{n_k}^{(k)} \right]^{\mathrm{T}} \tag{7}$$

Weight of element not in controlled of $j$ is zero, and make

$$p = \left[ p_1^{(k)}, p_2^{(k)}, \cdots, p_{n_{k-1}}^{(k)} \right] \tag{8}$$

This is a matrix of $n_k \times n_{k-1}$, which is a sort of element in the level of $k$ relative to element in the level of $k-1$. Then, for the overall destination, the rank vector of the element on the layer of $k$ is

$$w^{(k)} = \left[ w_1^{(k)}, w_2^{(k)}, \cdots, w_{n_k}^{(k)} \right]^{\mathrm{T}} = p^{(k)} w^{(k-1)} \tag{9}$$

or

$$w_i^{(k)} = \sum_{j=1}^{n_{k-1}} p_j^{(k)} w_j^{(k-1)} \tag{10}$$

And generally

$$w^{(k)} = p^{(k)} p^{(k-1)} \cdots w^{(2)} \tag{11}$$

Here $w^{(2)}$ is the sorting vector for second layers of elements to the total target.

## 5. Application of FAHP in Bidding Quotation for Petroleum Geophysical Prospecting Project

At present, there are many problems in the geophysical prospecting market, such as blind price reduction to get bid winning and the lack of effective quotation evaluation methods. Using FAHP on the basis of studying the bidding and bidding practice of geophysical exploration market can effectively guide the oil enterprises to strengthen the construction of project management, and accelerate China's petroleum geophysical exploration market and the international

market pace closer [5].

## 5.1. Overview of Bidding Evaluation of Petroleum Geophysical Prospecting Projects

With the shortage of oil in the whole world, China's competition in geophysical industry has become increasingly fierce. It also requires considerable technical level to seek for geophysical enterprises suitable for engineering construction to ensure the smooth progress of construction projects [6]. Therefore, it is of great significance to study the evaluation methods of petroleum geophysical prospecting project for the geophysical prospecting bidding practice of petroleum enterprises.

## 5.2. Quotation Evaluation of Petroleum Geophysical Prospecting Project by FAHP

Assuming the expert group select the unit which more excellent in the overall and having more reasonable price from three candidate bidders on the basis of five evaluation criteria, then it can be divided into five standard geophysical offer like this: direct costs, management fees, interest in independent fees, and other expenses, and each criterion is no longer divided into sub criteria. Then, using FAHP to determine the oil geophysical exploration production units can proceed from the following steps:

1) Establishing hierarchical structure, shown as **Figure 4**.

2) Determine the weights of the correlation coefficients by comparison of the criterion
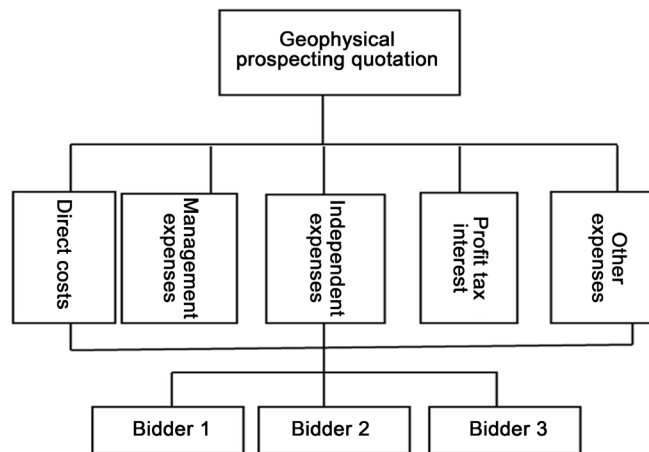
Here, suppose there are three panels of experts to identify the five indicators and get the following matrix, shown in **Table 2**.

According to the logarithmic least squares method to calculate the weight vectors of each criterion:

$$W = \begin{pmatrix} 0.3177 & 0.1230 & 0.1186 & 0.1230 & 0.3177 \end{pmatrix}$$

3) Evaluate bidders by single index and establish fuzzy judgment matrix

First determine use $V = \{v_1, v_2, \cdots, v_5\}$ as evaluation grades, followed by increasing the degree of satisfaction, shown in **Table 3**.



**Figure 4.** Simplified analytic hierarchy chart of petroleum geophysical prospecting price.

**Table 2.** Judgment matrix of Criterion.

| Score | Direct-cost | Management-expenses | Independent-expenses | Profit-tax-interest | Other-expenses |
|---|---|---|---|---|---|
| Direct-cost | (0.5, 0.5, 0.5) | (0.6, 0.7, 0.8) | (0.7, 0.8, 0.9) | (0.6, 0.7, 0.8) | (0.4, 0.5, 0.6) |
| Management-expenses | (0.2, 0.3, 0.4) | (0.5, 0.5, 0.5) | (0.5, 0.6, 0.7) | (0.4, 0.5, 0.6) | (0.2, 0.3, 0.4) |
| Independent-expenses | (0.1, 0.2, 0.3) | (0.3, 0.4, 0.5) | (0.5, 0.5, 0.5) | (0.3, 0.4, 0.5) | (0.1, 0.2, 0.3) |
| Profit-tax-interest | (0.2, 0.3, 0.4) | (0.4, 0.5, 0.6) | (0.5, 0.6, 0.7) | (0.5, 0.5, 0.5) | (0.2, 0.3, 0.4) |
| Other-expenses | (0.4, 0.5, 0.6) | (0.6, 0.7, 0.8) | (0.7, 0.8, 0.9) | (0.6, 0.7, 0.8) | (0.5, 0.5, 0.5) |

**Table 3.** Rating.

| $v_i$ | $v_1$ | $v_2$ | $v_3$ | $v_4$ | $v_5$ |
|---|---|---|---|---|---|
| Comment | Very satisfactory | More satisfactory | common | dissatisfactory | Very dissatisfactory |

The fuzzy judgment matrix of each bidder is obtained:

$$P_1 = \begin{bmatrix} 0.3 & 0.4 & 0.3 & 0 & 0 \\ 0 & 0.2 & 0.5 & 0.3 & 0 \\ 0.2 & 0.7 & 0.1 & 0 & 0 \\ 0.1 & 0.3 & 0.4 & 0.1 & 0.1 \\ 0.1 & 0.4 & 0 & 0.4 & 0.1 \end{bmatrix}$$

$$P_2 = \begin{bmatrix} 0.1 & 0.5 & 0.4 & 0 & 0 \\ 0 & 0 & 0.5 & 0.3 & 0.2 \\ 0.1 & 0.2 & 0.6 & 0.1 & 0 \\ 0.1 & 0.3 & 0.4 & 0.2 & 0 \\ 0 & 0.2 & 0.7 & 0.1 & 0 \end{bmatrix}$$

$$P_3 = \begin{bmatrix} 0 & 0.1 & 0.2 & 0.7 & 0 \\ 0 & 0 & 0.2 & 0.3 & 0.5 \\ 0 & 0.3 & 0.1 & 0.4 & 0.2 \\ 0 & 0.3 & 0.4 & 0.2 & 0.1 \\ 0.1 & 0 & 0.3 & 0.5 & 0.1 \end{bmatrix}$$

4) Using the weight vectors of each criterion obtained by the second step and the fuzzy judgment matrix obtained by the third step to calculate the evaluation result vectors of each bidder.

$$S = W \cdot P$$

$$S_1 = (0.16310, 0.39868, 0.21787, 0.17628, 0.04407)$$

$$S_2 = (0.05593, 0.28301, 0.53133, 0.10513, 0.02467)$$

$$S_3 = (0.03177, 0.10425, 0.24451, 0.49018, 0.12929)$$

5) Calculate the final score of each bidder in the evaluation result vector

$$T = \frac{\sum\limits_{j=1}^{m} s_j^k \cdot j}{\sum\limits_{j=1}^{m} s_j^k} \left( k = 2 \right)$$

$$T_1 = 0.314295, \quad T_2 = 0.461353, \quad T_3 = 0.412965$$

Because the smaller the T value calculated by the weighted average, the better the program, so it can be concluded that the bidder's 1 offer is optimal, the bidder 3 comes second, and the bidder's 2 offer is the most unreasonable. Then, in accordance with this sort of selection, we can select the bidder 1 to construct the petroleum geophysical prospecting project.

## 6. Conclusion

This paper mainly studies the method of analytic hierarchy process and fuzzy comprehensive evaluation method, and explained the principle and modeling process; it also talks about FAHP's principle and modeling method which is the combination of the analytic hierarchy process and fuzzy comprehensive evaluation method, and gets the detailed steps of the algorithm, then applies FAHP in bidding quotation for petroleum geophysical prospecting project and achieves good application effect.

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