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The Application of Analytic Hierarchy Process in Quantitative Research on Handwriting Examination

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ABSTRACT The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method combined with qualitative and quantitative analysis. Chinese handwriting examination too is a process of qualitative and quantitative decision-making. This paper attempts to use the AHP to quantitatively consider the process of handwriting examination and to find a convincing qualitative basis for the expert identification of handwriting.

KEY WORDS Document inspection; Chinese handwriting examination; Analytic Hierarchy Process; Quantification; Quantitative analysis; Multi-criteria decision-making method

In the field of document examination, the quantitative methods and ideas of Chinese handwriting examination are mostly based on computer mathematical models. However, it is always difficult to find an idealized model due to the complexity and variability of handwriting. The process of handwriting identification, largely based on empirical judgments, is actually a process wherein appraisers make operational decisions. In this paper, the Analytic Hierarchy Process (AHP) in operational research is used to construct a pattern that can reproduce the quantification process of appraisers' thoughts through a combination of qualitative and quantitative methods.

1. THE FEASIBILITY OF THE AHP IN QUANTITATIVE RESEARCH IN HANDWRITING EXAMINATION

1.1 The use of the AHP in the quantitative analysis of a complex decision-making process

The AHP was proposed by T. L. Saaty, an American operations expert [1]. It refers to a complex multi-criteria decision-making system. In this system, the target or a decision problem is first decomposed into a hierarchy of multiple objectives and multilevel indices through the qualitative index fuzzy quantification method. This is done to calculate hierarchical single sort (weight) and total ordering that can be used as a multi-scheme system to optimize the decision-making process. The AHP is a process in which a decision is made based on the general objective, the stated problem, and evaluation criteria after the problem is decomposed into different levels in a hierarchy. Using the eigenvector method, a judgment matrix is obtained for each element of each level to obtain the priority weights of the elements. Finally, the weighted sum method is used to obtain alternative solutions to reach the target weight, and this final weight is the optimal solution [2]. Here, the so-called "priority weight" is a relative measure, which indicates the evaluation of alternatives in specific measurement criteria or sub-goals, and of each element in the different hierarchical levels.

Its basic principle is dividing the factors involved in complex problems into several hierarchical levels, performing pairwise comparisons of the various elements of the same level according to some criteria, comparing their importance, and then calculating the weight of every element in each level. The optimal scheme is determined according to the combination and maximum weight principle.

This method is suitable for dealing with complex problems that are difficult to quantify as it involves a combination of qualitative and quantitative analysis. In the decision-making process, the qualitative thinking process is mathematical and model, and it helps maintain a consistent thought process. The method is used to construct a judgment matrix and find its maximum eigenvalue. The corresponding eigenvector, after normalization, is the importance weight of a certain level relative to that of the previous level. In this case, if you think of the matrix as a motion, the most important features are obviously its velocity and direction, and so the eigenvalue is the velocity of the motion, and the eigenvector is the direction of the motion. Its mathematical definition is as follows: A is an n-order matrix, if the number of λ and n for non-zero vector x, relation $Ax = \lambda x$, then the number of λ is the characteristic value and a non-zero vector x is called an eigenvector of A corresponding to the eigenvalue of λ.

1.2 Handwriting is vague and inconsistent

Handwriting examination tracks the movement of writing, which is not uniform or limited to two-dimensional space. It includes, among other things, writing pressure, speed, and angle, as well as change in the rhythm of these factors. In plane and static handwriting, we can observe a three-dimensional, dynamic image. From a single stroke, multiple connected strokes, word relationships, and text layout, we can understand the writing process of Chinese characters that includes writing pressure, speed, and other characteristics [3]. However, the writing movement is not precise and mechanical; even if the same word is repeatedly written in a row, it is quite impossible to produce the same stroke length, arc, angle, and distance between strokes. Therefore, handwriting is ambiguous, and it is inappropriate to measure its absolute value.

Moreover, handwriting does not always have a fixed form. When someone is writing, the person's mood, motivation, writing tools, and environmental conditions could change, and in some cases, a person may want to deliberately disguise his/her handwriting, so even the same person's handwriting can appear varied. In addition, handwriting consists of eight basic strokes, which are the basic units of text, and they are linked through writing movements. In the process of "linking" these strokes, the writing movements are broken and punctuated, and one can transform the font or even reduce or accelerate his/her writing speed [4].

The objective of handwriting examination is to analyze the character symbol system of personal handwriting. As mentioned earlier, handwriting is ambiguous, and it is difficult to measure it accurately. These complex and random characteristics of handwriting make handwriting examination a subjective cognitive process.

1.3 Qualitative and quantitative analysis in handwriting examination

In handwriting examination practice, an examiner compares two handwriting samples to determine whether it is written by the same person. It is important to identify whether the two samples are written by the same person, and to do that, the examiner needs to identify the handwriting characteristics and then compare them. Handwriting characteristics refer to the specific signs of an individual's handwriting, which is based on personal writing skills and habits, and these signs include the features of skill level, text layout, typos, proportion, and connectedness and disconnectedness, as well as font characters, pen marks, Arabic numeral features, and symbol characteristics [5]. In handwriting examination, different handwriting characteristics should be selected to carry out a comparison according to specific cases. This process includes analyzing the handwriting, selecting and comparing characteristics, performing comprehensive evaluation, and forming conclusions. In the same recognition theory, two samples are considered the same if they contain similar differences. In the handwriting examination theory, everyone's handwriting is considered peculiar, that is, it reflects personal writing habits, which are unique as well as common. In other words, even if two handwriting samples are written by the same person, they would contain differences based on different characteristics, and if they are written by different people, the samples could still have similar characteristics. Therefore, in the comprehensive evaluation phase, it is necessary to evaluate the quality and quantity of similarities and differences [6]. Through qualitative and quantitative analysis, one can determine whether two handwriting samples are written by the same person.

For decades, people have been struggling to find a way to use computer technology for handwriting recognition, but with little success. The use of computer technology for handwriting recognition has undeniably made breakthrough progress in artificial intelligence, digital image and signal processing, feature extraction, recognition algorithms, and measurement techniques, especially in the breakthrough of the automatic segmentation and location of significant Chinese characters. However, writing is a dynamic process, which is difficult to reproduce repeatedly. First, normal writing may undergo various changes due to writing speed, environment, instruments, and a writer's physical and psychological characteristics. Second, regarding intentionally disguised handwriting, due to writers' disguising skills and different level of ability, the difficulty of identification also varies. If writers' write could be careful planning, attention to detail, and deliberate control, they can dramatically change their handwriting. Third, at present, handwriting examination is mainly based on analyzing signatures. However, signatures contain fewer words, have little features, are arbitrary, have multiple changes, and can easily be imitated. Identification of signatures using computers to determine the characteristics of the handwriting and automatic handwriting recognition is very difficult.

1.4 The AHP is applied to quantification and decision-making in handwriting examination

The process of handwriting examination is essentially a decision-making process to determine whether two handwriting samples are written by the same person. Comparing two handwriting samples could lead to the following conclusions: written by the same person, written by different people, likely written by the same person, likely written by different people, and unable to make conclusions. When faced with a variety of options, experts need to compare, judge, and evaluate based on certain standards in order to reach a conclusion. The study of natural and social phenomena mainly uses mechanism and statistical analyses—the former analyzes the causal relationship between phenomena with classical mathematical tools, and the latter uses random mathematics as a tool to seek statistical laws through a large amount of observation data. A systematic analysis of recent developments is yet another method, and the AHP, being a practical method, is one of the mathematical tools used in systematic analysis.

2. THE CONSTRUCTION OF THE AHP IN QUANTITATIVE RESEARCH IN HANDWRITING EXAMINATION

Quantification in handwriting examination must be started with the characteristics of handwriting, including quantization of characteristic descriptions and values. The AHP's principle and method are introduced into quantitative analysis in handwriting examination, whose basic idea is to select the handwriting characteristics or extract the standard elements, to determine the value of the handwriting characteristics or conduct weight comparison of each standard element, and to perform a comprehensive evaluation or comparison of the decision-making process.

We combined the actual materials of a handwriting examination to introduce the specific application of the AHP. In the loan dispute case examined in this study, the number of words that need to be checked is large in the IOU ("I owe you"), the handwriting is normal, of sufficient quantity, close to "the condition required for inspection handwriting, and reflects that the writer's writing style is complete and stable.

2.1 Construction of a hierarchical diagram

First, a structural diagram of the AHP must be constructed. The first layer is the target layer that is, determining whether the two handwriting samples are written by the same person. The second layer is the standard layer; it involves analyzing the questioned handwriting and the sample handwriting and selecting the handwriting characteristics, for example, writing skill level, font feature, proportion feature, connectedness and disconnectedness feature, arrangement feature, etc. The third layer is the decision scheme layer that is, reaching the conclusion of handwriting examination.

2.2 Scale and pairwise comparison matrix

In order to make pairwise comparison of each scheme to get the relative weight under each standard or certain standard, we introduced the relative importance of scale, as shown in Table 1.

The reasons for choosing the 1-9 scale are as follows. Psychologists believe that too many factors of pairwise comparison will exceed the ability of people to judge; up roughly in the range of 7±2, such as the limit of 9, and 1-9 scales accurately express the difference between them [7]. The two factors in Table 1, i and j, represent two standards for comparison or two schemes for comparison under a certain standard. This pairwise comparison matrix is composed of the scale aij, and the score of the matrix should be given independently by the expert.

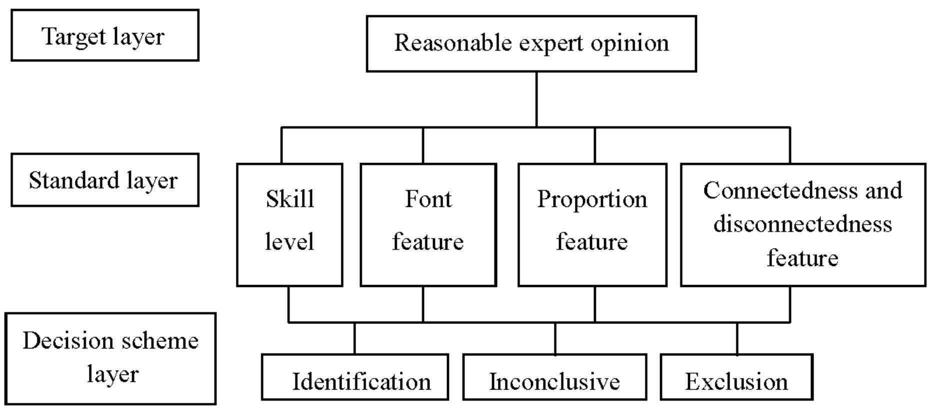

Fig. 1 Hierarchical diagram of handwriting examination

2.3 The process of calculating the weight of each factor of the standard layer under the target layer

2.3.1 Determining the standard weight

To obtain the relative importance (or relative weight) of each standard, pairs of four standards are formed for each comparison to get the pairwise comparison matrix. Table 2 shows the score of the handwriting characteristics selected by the appraiser for the case examined in this study.

The scoring rules are as follows: the appraiser selects the handwriting characteristics and, according to the 1-9 scale, scores the characteristics based on their significance, such as, when skill level vs. skill level, score is 1; when skill level is more important than font feature, score is 2; when skill level is slightly less important than proportion feature, score is 1/3; when skill level is obviously not important than connectedness and disconnectedness feature, score is 1/5. In the same way, all matrix judgments are completed.

The matrix calculation is conducted as follows:

The first step is to find the sum of each column in the comparison matrix, as shown in Table 3.

In the second step, every element of the pairwise comparison matrix is divided by the sum of the corresponding column, and the new matrix composed by the quotient is called the standard pairwise comparison matrix, as shown in Table 4.

The third step is to calculate the average of each row of the standard pairwise comparison matrix, which is the weight of each standard in the target layer, as shown in Table 5.

This method of calculating the weight of each factor is called the standard column average method, which is an approximate method for calculating weight. Other methods include the square root method, power multiplication method, *etc.* [8].

Table 1 Scale comparison

Scale a_{ij}	Definition
1	i factor and j factor are equally important
3	i factor is more important than j factor
5	i factor is obviously more important than j factor
7	i factor is very important than j factor
9	i factor is absolutely important than j factor
2,4,6,8	The scaled value corresponding an intermediate state between the above two judgments
Reciprocal	If j and i factors are compared, the judgment value is $a_{ji}=1/a_{ij}$

Table 2 Four standard comparison matrix

	Standard			
	Skill level	Font feature	Proportion feature	Connectedness and disconnectedness feature
Skill level	1	2	1 / 3	1 / 5
Font feature	1 / 2	1	1 / 4	1 / 4
Proportion feature	3	4	1	1 / 3
Connectedness and disconnectedness feature	5	4	3	1

Table 3 The sum of the pairwise comparison matrix for each column

	Standard			
	Skill level	Font feature	Proportion feature	Connectedness and disconnectedness feature
Skill level	1	2	1 / 3	1 / 5
Font feature	1 / 2	1	1 / 4	1 / 4
Proportion feature	3	4	1	1 / 3
Connectedness and disconnectedness feature	5	4	3	1
Column sum	19 / 2	11	55 / 12	107 / 60

Table 4 Standard pairwise comparison matrix

	Standard			
	Skill level	Font feature	Proportion feature	Connectedness and disconnectedness feature
Skill level	2 / 19	2 / 11	4 / 55	12 / 107
Font feature	1 / 19	1 / 11	3 / 55	15 / 107
Proportion feature	6 / 19	4 / 11	12 / 55	20 / 107
Connectedness and disconnectedness feature	10 / 19	4 / 11	36 / 55	60 / 107

Table 5 Average of each row of the standard pairwise comparison matrix

	Standard				
	Skill level	Font feature	Proportion feature	Connectedness and disconnectedness feature	Row average
Skill level	0.105	0.182	0.073	0.112	0.118
Font feature	0.053	0.091	0.055	0.140	0.085
Proportion feature	0.316	0.364	0.218	0.187	0.271
Connectedness and disconnectedness feature	0.526	0.364	0.655	0.561	0.526

Table 5 shows the scores or weights of the four standards under the target layer, which are 0.118, 0.085, 0.271, and 0.526 respectively, and the sum of the weights is 1. The vectors 0.118, 0.085, 0.271, 0.526 are called standard eigenvectors.

2.3.2 Consistency test of comparison matrix

The elements of the pairwise comparison matrix are obtained by a comparison of two factors, and in many of these comparisons, it is often possible to draw some inconsistent conclusions.

When the importance of factors such as *i*, *j*, and *k* is very close to each other, it may be concluded that i is more important than *j* in the pairwise comparison, *j* is more important than *k*, and *k* is more important than *i*, thereby drawing contradictory conclusions. This is more likely to occur when there are many factors, so it must be tested for consistency.

The consistency test is composed of five steps:

In the first step, the tested pairwise comparison matrix is multiplied by its eigenvectors. The result is called the empowerment sum vector, as shown below:

$$\begin{pmatrix} 1 & 2 & 1/3 & 1/5 \\ 1/2 & 1 & 1/4 & 1/4 \\ 3 & 4 & 1 & 1/3 \\ 5 & 4 & 3 & 1 \end{pmatrix} \times \begin{pmatrix} 0.118 \\ 0.085 \\ 1.271 \\ 0.526 \end{pmatrix} = \begin{pmatrix} 0.483 \\ 0.344 \\ 1.14 \\ 2.269 \end{pmatrix}$$

In the second step, each component of the empowerment sum vector is divided by the component of the corresponding eigenvectors, as in the following case:

0.483/0.118≈4.093, 0.344/0.085≈4.047

1.14/0.271≈4.207, 2.269/0.526≈4.314

In the third step, the average of the results obtained in the second step is calculated, and it is recorded as l_{max} , as follows:

$$l_{max} = \frac{4.093 + 4.047 + 4.207 + 4.314}{4} = 4.165$$

In the fourth step, the consistency index CI is calculated:

$$CR = \frac{4.165 - n}{n - 1}$$

n is the number of comparison elements; in this case, there are four standards, *n* = 4, so:

$$CR = \frac{4.165 - 4}{4 - 1} = 0.055$$

In the fifth step, the consistency rate CR is calculated:

$$CR = \frac{CI}{RI}$$

In order to determine the permissible range of the inconsistent degree of matrix, we need to find out the standard that can measure the matrix of the consistency index CI and need to introduce the random consistency index RI.

For *n* = 1, ..., 9, Saaty gives the value of RI, as shown in Table 6.

The value of RI is obtained by using the random method to construct 500 sample matrices: a number from 1 to 9 and its reciprocal is extracted to construct a positive reciprocal matrix, and the average of maximum eigenvalue

$\lambda_{max}^{'}$ is obtained, which is defined as follows:

$$RI = \frac{\lambda_{max}^{'} - \mathrm{n}}{\mathrm{n} - 1}$$

Generally, when CR ≤ 0.1, the consistency of the pairwise comparison matrix is acceptable; Otherwise, its consistency is poor, and then we must recalculate pairwise comparison judgments. In this case, we can calculate CR = 0.055/0.90 ≈ 0.061 ≤ 0.1, so the pairwise comparison matrix of four standards satisfies the consistency requirements, and the corresponding eigenvectors are valid.

2.4 The process of calculating the weight of each factor of the decision scheme layer under the single factor of the standard layer

Under the standard skill level, the pairwise comparison method is used to judge the significance of the pairs among the three schemes, and then the pairwise comparison matrix is concluded under this standard, as shown in Table 6. According to the pairwise comparison matrix, the weight of the three schemes under this standard is calculated, and then the consistency test is performed. The specific calculation method is the same as in the above standard layer calculation.

Using the same process, under the skill level, font feature, proportion feature, and connectedness and disconnectedness feature, we can construct the pairwise comparison judgment matrix among the "affirmation, non-conclusion, and exclusion" schemes. The judgment matrices and the calculation results are shown below (Tables 7-10).

The calculation results are as follows:

Eigenvectors of skill level = (0.6196,0.1561,0.2243), CI = 0.0546, CR = 0.0942 Eigenvectors of font feature = (0.7189, 0.1127, 0.1684), CI = 0.0437, CR = 0.0754

Eigenvectors of proportion feature = (0.7903, 0.1328, 0.0769), CI = 0.011, CR =0.0189

Eigenvectors of connectedness and disconnectedness feature = (0.6232, 0.2395, 0.1373), CI = 0.0092, CR = 0.0158

These weights or eigenvectors are used to solve the sequence of each scheme.

As mentioned above, the eigenvectors of the four standards and the four eigenvectors of the three schemes under the single standard are calculated, as shown in Table 11.

These weights or vectors are used to calculate the total score of each scheme.

Under skill level, the score of the affirmation scheme is 0.6196, and the importance of skill level in the target of reasonable expert opinion is 0.118; therefore, due to its skill level, the affirmation scheme in the total target score is 0.118 ×0.6196. Similarly, the affirmation scheme due to its font feature in the total target score is 0.085×0.7189; the affirmation scheme due to its proportion feature in the total target score is 0.271×0.7903; and the affirmation scheme due to its connectedness and disconnectedness feature in the total target score is 0.526×0.6232. Therefore, the total score of the affirmation scheme in the total target is as follows:

$$0.118 \times 0.6196 + 0.085 \times 0.7189 + 0.271 \times 0.7903 + 0.526 \times 0.6232 \approx 0.676$$

In the same way, the total score of the non-conclusion scheme in the total target is as follows:

$$0.118 \times 0.1561 + 0.085 \times 0.1127 + 0.271 \times 0.1328 + 0.526 \times 0.2395 \approx 0.190$$

The total score of the exclusion scheme in the total target is as follows:

$$0.118 \times 0.2243 + 0.085 \times 0.1684 + 0.271 \times 0.0769 + 0.526 \times 0.1373 \approx 0.134$$

By comparison, the score of the affirmation scheme is the highest.

Table 6 The average random consistency index

Dimensions (*n*)	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table 7 Pairwise comparison matrix of skill level

	Skill level		
	Affirmation	Non-conclusion	Exclusion
Affirmation	1	3	4
Non-conclusion	1 / 3	1	1 / 2
Exclusion	1 / 4	2	1

Table 8 Pairwise comparison matrix of font feature

	Skill level		
	Affirmation	Non-conclusion	Exclusion
Affirmation	1	5	6
Non-conclusion	1 / 5	1	1 / 2
Exclusion	1 / 6	2	1

Table 9 Pairwise comparison matrix of proportion feature

	Skill level		
	Affirmation	Non-conclusion	Exclusion
Affirmation	1	7	9
Non-conclusion	1 / 7	1	2
Exclusion	1 / 9	½	1

Table 10 Pairwise comparison matrix of connectedness and disconnectedness feature

	Skill level		
	Affirmation	Non-conclusion	Exclusion
Affirmation	1	3	4
Non-conclusion	1 / 3	1	2
Exclusion	1 / 4	1 / 2	1

Table 11 The eigenvectors of the four standards and of the three schemes under the single standard

Eigenvectors of the four standards		Eigenvectors of the three schemes under the single standard				
Skill level	0.118		Skill level	Typeface Feature	Proportion feature	Connectedness and disconnectedness feature
Typeface Feature	0.085	Affirmation	0.6196	0.7189	0.7903	0.6232
Proportion Feature	0.271	non-conclusion	0.1561	0.1127	0.1328	0.2395
Connectedness and disconnectedness feature	0.526	Exclusion	0.2243	0.1684	0.0769	0.1373

3 DISCUSSION AND CONCLUSIONS

First, the selection of skill level, font feature, proportion feature, and connectedness and disconnectedness feature in this study is based on a specific case. The different circumstances of the case are not limited to the four abovementioned characteristics. Different characteristics may be added or deleted according to specific circumstances and the standard layer. In addition, the sub-standard layer can be subdivided under the standard layer. For example, under the connectedness and disconnectedness feature, it can be subdivided into initial, connecting, and terminal strokes, and under the connecting strokes feature, it can be subdivided into slant or slope, speed, and pressure features. The three-tier structure can be extended to a four or even five-layer structure [9]. At the same time, the "affirmation, non-conclusion, and exclusion" schemes can be extended to the "affirmation, tendency affirmation, non-conclusion, exclusion, and tendency exclusion" schemes.

Using MATLAB software, the calculation of the abovementioned extended application can be realized.

Second, through a combination of qualitative and quantitative methods, this approach describes the thought process of experts using the mathematical form, that is, using data to explain identification and exclusion.

Third, the matrix judgment score was marked by analyzing the questioned and sample handwriting, and combining the appraiser’s professional experience and the difference in each case. In the implementation process, it is necessary to pass the consistency test; if the consistency test fails, it needs to be rescored.

Finally, the AHP has become a mature concept and an operational method. It is applicable to the field of handwriting examination. However, the specific operational practice needs to be studied further.

The mathematical algorithm of the AHP is programmed by MATLAB software, which is convenient for finishing the operation and consistency test of the above-mentioned matrix.

REFERENCES

[1] LIU Manfeng, TAO Changqi, LIU Jian. Operations Research Tutorial. Tsinghua University Press,Beijing,2010, pp. 465.
[2] Jin-yu Guo, Zhong-bin Zhang, Qing-yun Qun. The research and application of the analytic hierarchy process [J]. Chinese journal of safety science, 2008-05-15,
[3] Wang Yan. Introduction to handwriting line active sense in the application of handwriting identification [J]. Chinese Journal of forensic sciences, 2012-01
[4] Jiang-tao Feng. Details of handwriting characteristics extraction [J]. Chinese Journal of forensic sciences, 2008
[5] Wang Guanqing. Statistical analysis of handwriting characteristics [J]. Journal of criminal technology, 2003-04-30
[6] Zhi-hui Jia. Theory of handwriting identification of differences evaluation [J]. Chinese Journal of forensic sciences, 2009-8-15
[7] JIANG Qiyuan. Mathematical Model.3rd ed. Higher Education Press, Beijing, 2004, pp. 227-228.
[8］HAN Botang. Management Operational Research. Higher Education Press, Beijing, 2010, pp. 398.
[9] JIA Yuwen. Chinese Handwriting examination. Police Education Press, Beijing, 1999, pp. 112

Conflicts of interests

None declared.