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Analysis of the influencing factors and protection schemes of cultural relics protection based on multiple assessment models

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Abstract. The choice of a cultural heritage conservation scheme is crucial for the protection of cultural relics. A scientific cultural relics protection scheme can effectively reduce the risks and protection costs, and realize the sustainable and efficient development of cultural relics protection. In order to be able to choose the protection scheme more scientifically, this paper establishes an extreme weather risk assessment model based on the entropy weight method, a local underwriting value evaluation model based on grey prediction and other methods, and a cultural relics protection value evaluation model based on the entropy weight-fuzzy comprehensive evaluation method, and finally applies the results to the cultural relics protection scheme based on the analytic hierarchy process, so as to select a suitable protection scheme. This paper takes the protection of Tulou in Fujian Province as an example, and uses the model of this paper to analyze its protection scheme.

Keywords: Cultural relics preservation; Assessment model; Grey prediction; Fujian Tulou.

1. Introduction

The protection of important local cultural relics has always been one of the important tasks of local governments, and the protection and management methods of cultural relics have also undergone an iterative process [1], and the impact assessment of cultural relics protection has been widely used by countries around the world [2-3]. In practice, there are many factors that affect heritage conservation schemes, such as the increasing urbanization process [4] and the impact of extreme weather. In addition, there may be mutual influences and constraints between various factors, which brings great difficulties and complexities to the formulation of protection programs. For the analysis of the impact of relevant factors on the protection of cultural relics, there have been a few relevant studies.

Chang Haiqing [5] used the chromatography positive stacked bottom evaluation method ‖to qualitatively and quantitatively evaluate the multiple impacts of rail transit on cultural relics, and Xiong Nina [6] used WebGIS technology, a cultural relics management platform has been established to realize the function of cultural relics impact assessment. However, at this stage, most of the research still stays on the policy analysis of cultural relics protection, and there is no rational analysis of cultural relics protection, and there is no mature method that can comprehensively analyze the relevant factors of the protection plan. To make a more scientific and intuitive choice of protection schemes, this paper establishes a relevant model for the selection of cultural relics protection schemes.

In the protection of cultural relics, extreme weather often brings great risks to the protection of cultural relics, so this paper established extreme weather risk index E based on the entropy weight method. At the same time, insurance companies will help protect local cultural relics, so that the risk of the cost of cultural relics protection can be diversified. Therefore, based on the grey prediction GM (1,1) algorithm, establishing the local underwriting index M . The level of the conservation value of the cultural relics themselves is also a key factor to consider in the protection plan. In view of this situation, the cultural relics protection value index x was established based on the analytic hierarchy process and the fuzzy comprehensive evaluation method. Finally, the above indicators are used to analyze the analytic hierarchy process to determine the best scheme for cultural relics protection.

2. Mathematical models

2.1. Extreme weather risk assessment model

To visualize the possible risks of local extreme weather to cultural heritage conservation, this paper established a local extreme weather risk assessment model to quantify this indicator. Considering the differences in the probability of different extreme weather occurrences in the local area, establishing local extreme weather risk index E :

$$E = \sum_{k=1}^{x} P_k A_k \tag{1}$$

x is the number of extreme weather types. P_k is the average probability of occurrence of a certain extreme weather in the region in the past five years.

A_k is the risk assessment value of this kind of extreme weather, getting it by the entropy weight method. Based on the impact of extreme weather, taking the duration of extreme disasters a_1, the economic losses caused a_2, and the number of victims a_3 as the evaluation indicators, and the time of the past five years is the evaluation object.

Calculate the weight of the number i evaluation object on the number j indicator first:

$$p_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

i is the number of items of the evaluation object, j is the number of items of the evaluation index, n is the number of the evaluation object, and set $n = 10$ here. a_{ij} is the normalized value of the evaluation index for the evaluation object.

The entropy of the number j index can be obtained by equation(3):

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln p_{ij} \tag{3}$$

Then, can get the coefficient of variation of the number j index by equation $g_j = 1 - e_j$, next the weight of the index w_j can be calculated:

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \tag{4}$$

m is the number of evaluation index, and value is $m = 3$ here.

Based on the equation (4), the comprehensive evaluation value s_i of the number i evaluation object can be calculated:

$$s_i = \sum_{j=1}^{m} w_j p_{ij} \tag{5}$$

Finally, can get the risk assessment value of this extreme weather:

$$A = \sum_{i=1}^{n} s_i \tag{6}$$

2.2. Local underwriting value assessment model

Insurance is a very important part of heritage conservation. Insurance greatly improves the resilience of cultural relics to risks and their ability to recover after disasters [7]. For insurance companies, whether they can make a profit locally is the most important indicator to consider whether to underwrite. Therefore, this paper established a local underwriting index M to assess whether the insurer should underwrite locally.

The local underwriting index M is defined as:

$$M = NS\left(rn - \bar{h}L\left|p-1\right|\right) \tag{7}$$

n is the average income interest rate of the insurance company, and N is the number of local population. p is the ratio of the average annual number of extreme weather disasters in the future policy period to the average annual number of extreme weather disasters in the previous 10 years, and L is the local policy productivity.

r is a premium under a type of coverage, and it is defined as $r = \bar{h}cb$. Among them, c is the rate of insurance, it is generally 0.05%-2%; b is the duration of the insurance and $\bar{h}$ is the average property value in the local area. Since the insurance company pays out mostly the value of the insured property, using the average local property value $\bar{h}$ as the average payout.

2.2.1. Use GM (1,1) method to calculate average occurrence probability of extreme weather $\boldsymbol{p}$.

For historical data on the occurrence of extreme weather in previous years $x^{(0)}(k), k \in N^+$, reference series $\boldsymbol{x}^{(0)}$ can be generated:

$$\boldsymbol{x}^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)\right) \tag{8}$$

To use the grey prediction method to predict future data, it's necessary to test the data columns first. Setting the scale of the reference series is $\lambda(k)$. if all the scales $\lambda(k)$ fall into the range $\boldsymbol{\Omega} = (e^{-2/(n+1)}, e^{2/(n+1)})$, the reference series are considered to be suitable for GM (1,1) prediction.

Then can get 1-AGO sequence $\boldsymbol{x}^{(1)}$ by equation(8), and obtain the mean generation sequence $\boldsymbol{z}^{(1)}$ by 1-AGO sequence $\boldsymbol{x}^{(1)}$.

Next, establishing the GM (1,1) model, the predicted value $\hat{x}^{(1)}(k+1)$ can be obtained:

$$\hat{x}^{(1)}(k+1)=\left(x^{(0)}(1)-\frac{\hat{b}}{\hat{a}}\right)e^{-\hat{a}k}+\frac{\hat{b}}{\hat{a}},k=0,1,\cdots,n-1,\cdots \tag{9}$$

For the index $\hat{a},\hat{b}$, it can be solved through the following process. Define three matrices:

$$\boldsymbol{u}=\begin{bmatrix} a \\ b \end{bmatrix},\boldsymbol{Y}=\begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix},\boldsymbol{B}=\begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix} \tag{10}$$

Can get the resulting estimate $\hat{\boldsymbol{u}}$ of $\boldsymbol{u}$:

$$\hat{\boldsymbol{u}}=\begin{bmatrix} \hat{a} \\ \hat{b} \end{bmatrix}=\left(\boldsymbol{B}^{\mathrm{T}}\boldsymbol{B}\right)^{-1}\boldsymbol{B}^{\mathrm{T}}\boldsymbol{Y} \tag{11}$$

At this point, can calculate the future prediction of the probability of extreme weather occurring.

2.2.2. Calculation of policy efficiency L .

This paper considers the relevant factors about L are the cost that insurers use to develop risk mitigation plans and raise risk awareness for their clients Q, the local housing structure safety index Z, and extreme weather risk index E.

When insurers consciously promote the establishment of risk mitigation plans for their customers and improve their awareness of risk prevention, they can reduce the losses suffered by customers in extreme weather disasters. So, can get the following relation: $L \propto 1/Q^{\vartheta}$. ϑ is a constant.

The higher the safety index of the house, the stronger its ability to resist disaster damage, the lower the probability of damage in disasters, and the lower the efficiency of the insurance policy. Then, can get: $L \propto 1/Z^{\tau}$, τ is also a constant.

The higher the extreme weather risk indicator, the greater the impact of extreme weather in the region, and the higher the policy loss ratio in the region. Can get the relation: $L \propto E^{\kappa}$, κ is a constant.

To sum up, the expression of policy efficiency is:

$$L=jE^{\kappa}+k\frac{1}{Q^{\vartheta}}+l\frac{1}{Z^{\tau}} \tag{12}$$

The constants j,k,l reflect the degree to which the three indicators affect the efficiency of policy issuance.

2.2.3. Calculation of willingness to enroll S .

For the willingness to enroll, the main factors to consider are the extreme weather risk index E, the local economic level index G (local GDP/GDP of the region with the highest global GDP*100%) and the insurance loss ratio T (the amount of compensation paid/premium income*100%).

An increase in extreme weather risk indicators means that disasters are more likely to occur and the losses they can cause, making insurance more attractive. Therefore, considering: $S \propto E^{\xi}$, ξ is a constant.

There is a similar effect on insurance loss ratios. When the insurance loss ratio increases, the willingness of local residents to underwrite will also increase accordingly, and the normalized index of the local average three-year loss ratio t is as:

$$t = \frac{c_{\min} b_{\min} (T c_{\max} b_{\max} - 1)}{c_{\max} b_{\max} - c_{\min} b_{\min}} \tag{13}$$

Among them, $c_{\max}, b_{\max}$ is the maximum period of the highest rate and the duration of the warranty period, and $c_{\min}, b_{\min}$ is the minimum period of the lowest rate and the duration of the warranty period. This paper assumes the rate-related parameters $c_{\min} = 0.05\%$, $c_{\max} = 2\%$. the insurance period $b_{\min} = 1$, $b_{\max} = 100$ (unit: year).

After obtaining the normalization index, can get: $S \propto t^{\psi}$, ψ is also a constant, indicating the degree of influence of the underwriting rate on the willingness to participate in insurance.

In economically developed areas, people have a relatively good sense of risk prevention and underwriting. However, when the economy is highly developed, the growth of people's demand for insurance will slow down, because people's insurance coverage is already very high, and people with high income levels are more inclined to diversify their risks. Therefore, setting the local economic level and the willingness to participate in the premium rate satisfying relation: $S \propto \ln\left[G\left(e-1\right)+1\right]$.

To sum up, the willingness to participate in insurance satisfies the following relation:

$$S = \frac{\eta E^{\xi} + \theta t^{\psi} + \nu \ln\left[G\left(e-1\right)+1\right]}{\eta + \theta + \nu} \times 100\% \tag{14}$$

η, θ, ν are constants, reflecting the extent which they affect the degree of willingness to enroll.

2.3. Conservation value assessment model

For a cultural relic of great significance, the value it contains and the wealth it brings to people are immeasurable, let alone measured by money. This characteristic of cultural relics makes it difficult to quantify their conservation value. Based on this characteristic, using the analytic hierarchy process-fuzzy comprehensive evaluation method to establish a model for evaluating the value of cultural relics protection.

When considering the value of cultural relics, there are not only historical, artistic, and scientific values in the cultural relics value system, but also architectural characteristics, architectural functions, place spirit, scale volume, landscape planning, and other characteristics [8]. This paper mainly considers the following value factors: historical value B_1 , cultural value B_2 , social value B_3 , and scarcity B_4 .

2.3.1. The analytic hierarchy process to determine the weights.

To avoid the adverse effects of subjective factors on judgment, using analytic hierarchy process to determine the weight of different factors.

Firstly, comparing several factors B_1, B_2, B_3, B_4 in pairs to obtain a judgment matrix $\boldsymbol{B}$, and then can obtain its maximum eigenvalue $\lambda_{\max}$, so that the consistency index can be obtained by:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{15}$$

n is the order of the square matrix $\boldsymbol{B}$, RI can be obtained by looking up the table, and the consistency ratio CR is calculated by:

$$CR = \frac{CI}{RI} \tag{16}$$

If $CR < 0.1$, the consistency of the judgment matrix $\boldsymbol{B}$ is acceptable. Otherwise, the judgment matrix needs to be readjusted. After passing the consistency test, the weights used for fuzzy comprehensive evaluation $\boldsymbol{A}$ can be obtained.

2.3.2. The fuzzy comprehensive evaluation method to determine the protection value index x.

For the vague comprehensive evaluation of the value of cultural relics protection, taking the set of factors $U = \{u_1, u_2, u_3, u_4\}$, u_1 is historical value, u_2 is cultural value, u_3 is social value, and u_4 is scarcity.

A collection of comments is taken as $V = \{v_1, v_2, v_3, v_4, v_5\}$, v_1 is the conservation value is very high, v_2 is the conservation value is high, v_3 is the conservation value is medium, v_4 is the conservation value is common, and v_5 is the conservation value is low.

Let the number of grades of the comment set be m and the number of index be n , and the fuzzy comprehensive judgment matrix is as follow:

$$\boldsymbol{R} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \tag{17}$$

Finally, doing the matrix synthesis:

$$\boldsymbol{F} = \boldsymbol{A}\boldsymbol{R} \tag{18}$$

The largest value in $\boldsymbol{F}$ is selected as the evaluation result of the fuzzy comprehensive evaluation.

The cultural relics protection value index x is a qualitative index, and in order to quantify it continuously, taking the large Cauchy distribution and the logarithmic function as the membership function:

$$f(x) = \begin{cases} \left[1 + \chi(x - \delta)^{-2}\right]^{-1} & 0 \le x \le 0.6 \\ a \ln x + b & 0.6 \le x \le 1 \end{cases} \tag{19}$$

In order to determine the constant value χ, δ, a, b in the membership function, assuming that the membership is 1 when the "conservation value is high" and 0 when the "conservation value is high". When the "conservation value is very low", the membership is 0.01, then you can get the value: $\chi = 1.1086, \delta = 0.8942, a = 0.3915, b = 0.3699$. Function image is as Figure1 shown:

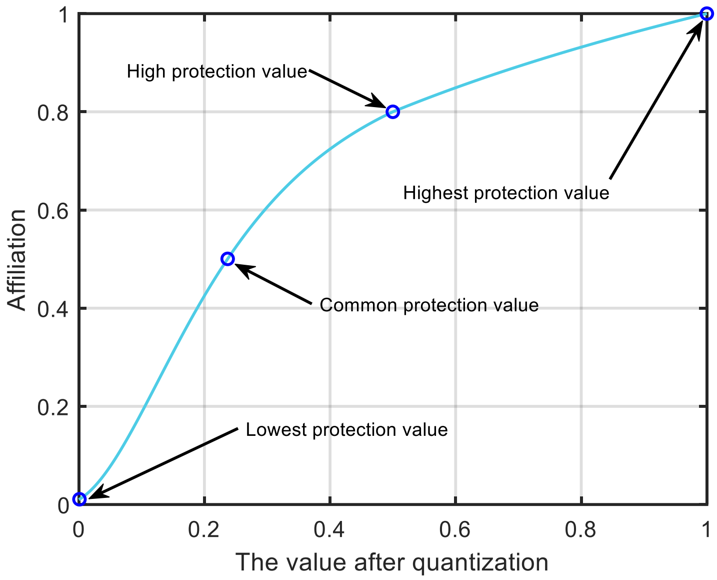

Figure 1. The membership function of the cultural relics' protection value index

3. Analysis of Tulou Protection Schemes in Fujian, China

Fujian Province is in the southeast coastal region of China, and has many cultural relics and monuments with Chinese cultural characteristics, but their protection is also affected by adverse factors such as extreme weather. The typical cultural relics of Fujian province, the Tulou, contains the practical value of architecture and rich cultural functions [9], so this paper selects the Tulou in Zhangzhou, Fujian Province as an example, and used the model established in this paper to analyze its conservation scheme. The regional data in the model solution are from the *Zhangzhou Statistical Yearbook* from 2013 to 2022 [10], and the extreme weather data are from the official website of the China Meteorological Administration [11].

3.1. Extreme weather risk index *E*

The types of extreme weather in Fujian mainly include typhoons, heavy rains, high temperatures and thunderstorms. This paper selected these four extreme weather indicators as metrics for calculating the extreme weather risk index E. Importing locally relevant climate data and standardize it. Next, after the entropy weight method is calculated, the comprehensive score of each extreme weather can be obtained the probability of occurrence of each extreme weather and the risk assessment value, they are showed in Table1:

Table 1. The probability of occurrence of extreme weather and its risk assessment value

	Typhoon	Rainstorm	High temperature	Thunderstorm
P_k	0.0881	0.1355	0.1423	0.6341
A_k	0.0204	0.0581	0.0872	0.8343

Based on the table above, can obtain extreme weather risk index E for the Zhangzhou region of Fujian Province is 0.551.

3.2. Local underwriting index *M*

According to the data, the economic level index G in Zhangzhou is 0.041, the population N is 5.05(unit: million people), the average property value $\bar{h}$ is 1.32 million RMB, the housing structure safety index $Z = 0.92$, and the average annual income interest rate of insurance companies n is 155%.

If the insurance period for Tulou cultural relics $b = 3$, the premium rate $c = 2\%$, and the cost to improve the local risk resistance Q is 1.8 million RMB.

Next, using GM (1,1) Model to predict the probability of extreme weather occurring. Predicted outcome is as Figure2 shown:

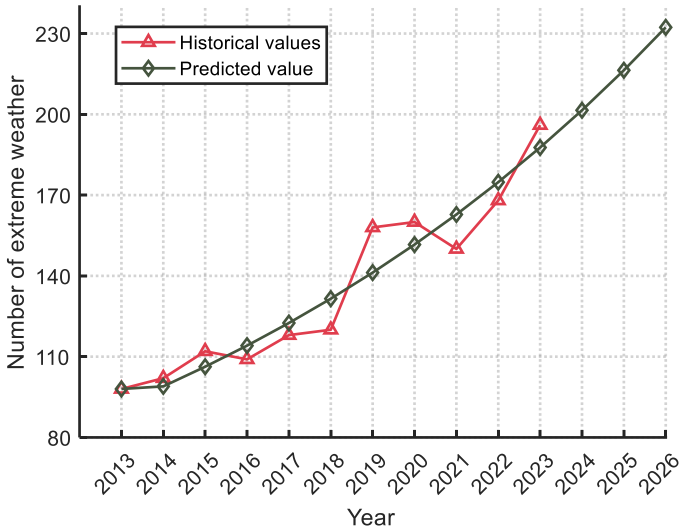

Figure 2. Prediction of the number of future extreme weather occurrences

The gradation deviation of the GM (1,1) model is 0.1725, which indicates that the model has certain feasibility and accuracy in predicting the number of extreme weathers. According to the prediction results, can know $p = 1.599$.

After calculation, the willingness to insure in Zhangzhou S is 32.2%, Policy efficiency L is 15.0%. Substitute the above data into the formula (7), can get the local underwriting index of Zhangzhou City $M = 0.665$.

3.3. Cultural relics protection value index x

First, using the analytic hierarchy process to determine the weight of the fuzzy comprehensive evaluation. The judgment matrix can be obtained:

$$\boldsymbol{B} = \begin{bmatrix} 1.000 & 4.000 & 5.000 & 2.000 \\ 0.250 & 1.000 & 2.000 & 0.333 \\ 0.200 & 0.500 & 1.000 & 0.200 \\ 0.500 & 3.000 & 5.000 & 1.000 \end{bmatrix} \tag{20}$$

Its maximum eigenvalue is $\lambda_{\max} = 4.057$, and the consistency index can be obtained:

$$CI = \frac{\lambda_{\max} - n}{n - 1} = 0.018 \tag{21}$$

Then, can get $RI = 0.89$, and the consistency ratio is further calculated:

$$CR = \frac{CI}{RI} = 0.021 < 0.1 \tag{22}$$

Therefore, the consistency of the matrix $\boldsymbol{B}$ is acceptable.

The weights used for fuzzy comprehensive evaluation is:

$$\boldsymbol{A} = \begin{bmatrix} 0.4835 & 0.1235 & 0.0737 & 0.3192 \end{bmatrix} \tag{23}$$

Take the normalized fuzzy judgment synthesis matrix:

$$\boldsymbol{R} = \begin{bmatrix} 0.12 & 0.43 & 0.27 & 0.13 & 0.05 \\ 0.29 & 0.26 & 0.37 & 0.08 & 0.00 \\ 0.21 & 0.35 & 0.18 & 0.19 & 0.07 \\ 0.15 & 0.23 & 0.37 & 0.17 & 0.08 \end{bmatrix} \tag{24}$$

Eventually, can get a collection of comments:

$$F = \begin{bmatrix} 0.157 & 0.339 & 0.308 & 0.141 & 0.055 \end{bmatrix} \tag{25}$$

It can be judged that the protection value of the Tulou is high. By substituting the results into the membership function, the quantified cultural relics protection value index $x = 0.642$.

3.4. Selection of protection scheme based on analytic hierarchy process

3.4.1. Model building.

To make the protection scheme of high-value buildings more scientific, targeted and economical, this paper established a protection scheme selection method based on analytic hierarchy process.

When considering the protection options, the evaluation criteria should fully consider the characteristics of the objects to be protected, and follow the principles of objectivity, science, and integrity [12]. In this paper, the following guidelines are considered: the risk index of the location, the local insurance index, the conservation value of the cultural relics, the average annual maintenance cost, and the social benefits it brings. Based on the above analysis, having established the basic model of analytic hierarchy, it is shown in Figure3:

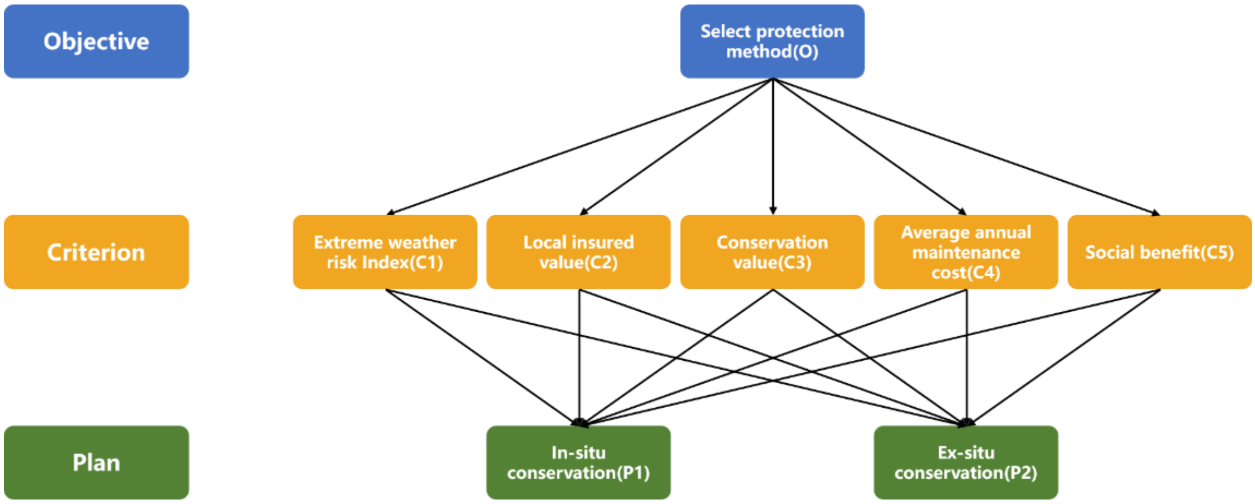

Figure 3. Schematic diagram of the protection scheme analytic hierarchy model

3.4.2. Model solving.

First, constructing a judgment matrix $O-C$ based on the results of the model solution in the previous section:

$$O-C=\begin{bmatrix} 1.00 & 1.20 & 0.60 & 1.40 & 1.00 \\ 0.80 & 1.00 & 0.50 & 0.90 & 0.60 \\ 1.60 & 2.00 & 1.00 & 1.20 & 1.00 \\ 0.70 & 1.10 & 0.85 & 1.00 & 0.80 \\ 1.00 & 1.65 & 1.00 & 1.25 & 1.00 \end{bmatrix} \tag{26}$$

Then, getting the eigenvalues $\lambda_{\max}=5.024$. And $CI=0.0059$, the consistency ratio CR is 0.0053. $CR<0.1$, so the consistency test passed. At the same time, can get the weight vector:

$$\omega_c=\begin{bmatrix}0.198 & 0.144 & 0.258 & 0.173 & 0.226\end{bmatrix}^{\mathrm{T}} \tag{27}$$

In the same way, building the program layer P with decision-making layers C of the judgment matrix $(C-P)_i$. i is the number of elements at the decision-making level. Each judgment matrix weight vectors are as the Table2 shown:

Table 2. Determine the weight vector of the matrix

i	1	2	3	4	5
ω_{p1}	0.6078	0.6815	0.7500	0.3333	0.1667
ω_{p1}	0.3922	0.3185	0.2500	0.6667	0.8333

To sum up, the weights of the two schemes are: $P1=0.508, P2=0.492$ .Therefore, for the protection of Fujian Tulou, it is more reasonable to choose the scheme of in-situ protection.

4. Conclusion

In this paper, establishing the extreme weather risk assessment models, local underwriting value assessment models, and cultural relics protection value assessment models, and set the extreme weather risk index E, the local underwriting index M and the cultural relics protection value index x. The three indicators obtained are used in the analytic hierarchy process of the cultural relic's protection program, to obtain the appropriate cultural relics protection program. Next, this paper takes Tulou in Fujian Province, China as an example, uses the established model to analyze its suitable protection scheme, and draws the conclusion that in-situ conservation is more suitable for Tulou protection.

From the results, the conclusions obtained in this paper are consistent with the actual Tulou protection schemes, so the model established in this paper has certain reference value for the actual selection of cultural relics protection schemes. At the same time, this paper quantitatively analyzes the influencing factors that are difficult to analyze in the protection of cultural relics, which can reflect their impact on the protection of cultural relics in a more scientific and intuitive way.

However, there are some parameters that need to be determined by many examples, and too few examples may cause these parameters to deviate from the actual situation. At the same time, there are many factors that affect the selection of cultural relics protection, and this paper only selects some important indicators, and does not fully consider all factors, which may also lead to some discrepancies between the model conclusions and the reality.

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