

Building Value Assessment and Protection Model under Catastrophe Risk

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Abstract. In recent years, with the change in the global environment, the frequency of catastrophes has been increasing, which poses a great threat to people's property and life safety. Many landmark buildings have high historical or economic value, and it is important to assess the value of these buildings and develop conservation plans. To evaluate the value of the building, this article first established the POT model to evaluate the risk of the building location. Then, based on the EWM-AHP method, we selected the first-level indicators and the second-level indicators to establish the value evaluation model of the building and used the logic function to establish the protection model through data fitting. According to the comprehensive analysis of the risk assessment and the value assessment of the building, the building protection measures are divided into three types: unprotected, reinforced, and relocated. It is applied to the church of San Marco in Venice, and it is concluded that the area needs to be reinforced. The establishment of the model is of great significance to the evaluation and protection of buildings.

Keywords: Risk Management, EWM-AHP, Catastrophe Risk, Value Assessment.

1. Introduction

At present, extreme climate disasters occur more and more frequently, and many buildings are at risk. It is urgent to protect buildings. To determine how to protect them, it is important to first understand the value of the building and determine what kind of conservation approach to take. However, there are few models for building value assessment and protection. A. J. Prieto and V. Vásquez [1] proposed the protection of historical buildings, defined the value of cultural heritage protection with the DDU-240 standard, defined the functional service life model, and also used the method of expert evaluation and scoring. Ünel F B [2] proposed a framework for building safety risk assessment using the AHP method.

This article intend to use the entropy weight method and analytic hierarchy process to evaluate the value of buildings. The analytic hierarchy process is a structured multi-attribute decision-making method. We use this method to synthesize multiple indicators and combine expert surveys to finally obtain the value evaluation results. We first applied the POT model to measure the extreme risk and obtained the probable maximum loss (*PML*). Based on a large number of literature and relevant research results, we put forward the use of cultural factors, economic factors, historical factors, and social factors as well as a total of 10 secondary indicators under these factors, combining qualitative analysis with quantitative analysis, and established our Comprehensive Value Evaluation Index Table. Then, we adopt the EWM-AHP algorithm, introduce the risk cost coefficient and meaning index to establish the model, and give specific protection measures by combining the results of our model.

Finally, we apply the model to Venice, evaluate its value, and conclude that our recommended conservation measures are reinforcement. Through the online survey, we found that our results are consistent with the measures being taken by the local government, which proves the effectiveness of our model.

2. Model establishment

2.1. POT Model

To quantify the catastrophe risk value of a certain region, based on this feature, we decided to build a Peaks Over Threshold (POT) model based on Generalized Pareto Distribution (GPD).

The GPD distribution is a series of continuous probability distributions. It can usually model the fat-tail, and POT is to model all the data in the observation that exceeds a certain threshold value. The POT model based on GPD distribution is more widely used in practice, and the model is established through the following three steps:

Step 1, the general distribution of it is:

$$G_{\xi, \beta}(y) = \begin{cases} 1 - \exp\left(-\frac{y}{\beta}\right) & , \xi = 0 \\ 1 - \left(1 + \frac{\xi \cdot y}{\beta}\right)^{-\frac{1}{\xi}} & , \xi \neq 0 \end{cases} \quad (1)$$

where ξ, β are the parameters, calculated by moment estimation method, when $\xi \geq 0, \beta \geq 0$; When $\xi < 0, 0 \leq y \leq -\beta/\xi$. When $\xi > 0$, GPD is fat-tailed.

Let μ be a sufficiently large threshold and the number of samples exceeding μ be N_μ . After the threshold value μ is determined, the excess loss distribution $F(\mu)$ can be estimated by the historical simulation method with $(n - N_\mu)/n$, and then the excess population distribution function of the random variable X_i can be determined:

$$\begin{aligned} F(X) &= G_{\xi, \beta}(y) (1 - F(\mu)) + F(\mu) \\ &= 1 - \frac{N_\mu}{n} \left[1 + \frac{\xi}{\beta} (x - \mu) \right]^{-\frac{1}{\xi}} \end{aligned} \quad (2)$$

Step 2, determine the threshold value μ , the determination of μ is a prerequisite for the accurate estimation of the possible maximum loss (*PML*) value. We use the method of testing the GPD model to determine the threshold [3]. Suppose that the random samples $X_1, X_2, \dots, X_n$ come from the GPD model (1), the parameters ξ and β are calculated using matrix estimation. For $i = 1, 2, \dots, n$, calculate $Z_i = F(X_{n,i})$ according to equation (2), where $X_{n,1}, X_{n,2}, \dots, X_{n,n}$, n is the order statistic of $X_1, X_2, \dots, X_n$.

Calculate the statistics W^2 and A^2 according to Shao T Y's, Ran H G's method [4]:

$$W^2 = \sum_{i=1}^n \left[Z - \frac{2i-1}{2n} \right]^2 + \frac{1}{12n} \quad (3)$$

$$A^2 = -n - \frac{1}{n} \sum_{i=1}^n (2i-1) [\ln Z_i + \ln(1 - Z_{n+1-i})] \quad (4)$$

Check the GPD test value table [5], and under a certain significance level α , repeat step 1 and 2 to get the threshold value μ and the excess number N_μ .

Step 3, According to Cebrian's [6] method, *PML* is estimated:

$$PML_\xi = \mu + \left[\left(-\frac{\lambda}{\ln(1-\varepsilon)} \right)^\xi - 1 \right] \frac{\beta}{\xi} \quad (5)$$

where ε is an arbitrarily small positive number, $\lambda = N_u/n$ is the intensity of the Poisson distribution, and n is the number of years observed.

Through this process, it can be calculated that the probability of loss exceeding PML is ξ , here we establish a relationship between the probability of occurrence and the loss value.

2.2. EWM(Entropy Weight Method)

The data of different indicators must be normalized to compare on the same scale because of their different specific values. For those indicators that bigger is better, that is, positive indicators, we adopt the following approach:

$$\tilde{x}_{ij} = \frac{x_{ij} - \min\{x_{ij}\}}{\max\{x_i\} - \min\{x_i\}} \quad (6)$$

After the above steps are completed, we further normalize the data:

$$p_{ij} = \frac{\tilde{x}_{ij}}{\sum_{j=1}^m \tilde{x}_{ij}} \quad (7)$$

Entropy is calculated as follows:

$$E_i = \frac{\sum_{j=1}^m p_{ij} \cdot \ln p_{ij}}{\ln m} \quad (8)$$

Further, calculate the weight w_i of the evaluation index we defined before as follows:

$$w_i = \frac{1 - E_i}{\sum_{i=1}^n (1 - E_i)} \quad (9)$$

We define the “evaluation vector” and the “influence degree vector” to represent the evaluation value:

$$\vec{\Phi} = (\phi_1, \phi_2, \dots) \quad (10)$$

$$\vec{S} = (S_1, S_2, \dots) \quad (11)$$

Finally, the evaluation is calculated as follows:

$$Score_x = \vec{\Phi} \cdot \vec{S} = \sum_{i=1}^{Num_x} \phi_i \cdot S_i \quad (12)$$

2.3. Determination of the meaning index

We define the risk cost factor as follows:

$$\Omega = \frac{PML}{G \cdot M} \quad (13)$$

where G represents local GDP per capita, M represents local population.

We define a meaning index that way:

$$V = \frac{K \cdot Q_p}{K \cdot Q_p + \lg Q_n} \cdot \Omega \quad (14)$$

where K is the impact of conservation measures on tourism, cultural values, etc., Q_p represents the positive impact factor and Q_n represents the negative impact factor, the clustering is carried out by the K-means method.

Through the determination of the above indicators, we can judge whether each indicator is a positive indicator or a negative indicator [7]. Among them, CDP is the easiest to quantify and the only negative indicator, so we defined it:

$$Q_{neg} = CDP \quad (15)$$

The next step is to calculate Q_{pos} , we get Q_{pos} by calculating the weights of the remaining 9 secondary indicators:

$$Q_{pos} = \sum_{i=1}^{Num_{pos}} Indicator_i \cdot w_i \quad (16)$$

where $Indicator_i$ is the i -th positive indicator, w_i is the weight corresponding to these secondary indicators, $NUM_{positive}$ is the number of these positive indicators.

3. Results

3.1. Process steps

We first applied the POT model to measure the extreme risk, and obtained the probable maximum loss (PML). Based on a large number of literature and relevant research results, we put forward the use of cultural factors, economic factors, historical factors, and social factors as well as a total of 10 secondary indicators under these factors, combining qualitative analysis with quantitative analysis, and established our Comprehensive Value Evaluation Index Table, as shown in Table1 and Table 2. Then, we first apply EWM to each dimension through objective data to obtain the weights of each positive and negative indicator, as shown in Table 3. For the weights of these four first-level indicators, we use the analytic Hierarchy Process (AHP) to get their values as 0.43774, 0.12745, 0.17077 and 0.26606 respectively. Next, the consistency test is carried out, and the results are shown in Table 4. The calculation results of the AHP show that the maximum feature root is 4.094, and the corresponding RI value is 0.882 according to the RI table, so $CR=0.036<0.1$, passing the consistency test. Finally, we introduce risk cost coefficient and meaning index to establish the protection model. According to the K-means clustering results and literature, we divide the protection of buildings into three types: no protection, reinforcement and relocation. When V is 0 to 0.3, choose not to protect the building; When V belongs to 0.3-0.8, choose to strengthen the building; When V belongs to 0.8 to 1, select the transfer building. The details are shown in Figure 1.

Finally, we apply the model to Venice, evaluate its value, and conclude that our recommended conservation measure is reinforcement. The result is shown in Table 5. Through the online survey, we found that our results are consistent with the measures being taken by the local government, which proves the effectiveness of our model.

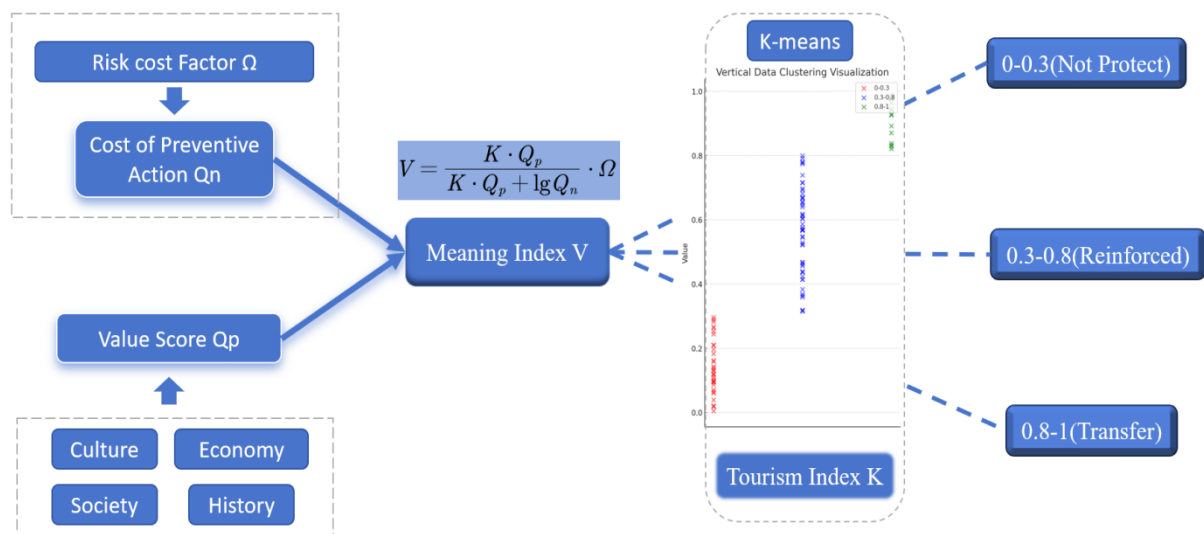


Figure 1. Construction of V

3.2. Indicators Determination

According to a large number of literatures and related research results [8-9], we find that the evaluation results of architectural value mainly depend on four aspects: economy, culture, history and society, and its culture, history and social value are difficult to be objectively quantified. Therefore, we use these four aspects as first-level indicators.

Next, we partially quantified the degree of each index, and established our comprehensive value evaluation index table with a scoring method [10-11], so as to calculate the value by combining qualitative analysis and quantitative analysis.

Table.1. Indicators Selected

Object	Indicator	Description
Culture	CI	Cultural Identity
	AV	Artistic Value
	FCA	Frequency of Cultural Activities
	OV	Own Value
Economy	CDP	Cost of Disaster Prevention
	IOT	Impact on Tourism
History	CHE	Correlation of Historical Events
	BA	Building Age
Society	PS	People's Satisfaction
	SI	Social Influence

Table.2. Comprehensive Value Evaluation Index Table

Object	Indicator	10 to 8 points	7 to 5 points	4 to 2 points	1 to 0 points
Culture	CI	Very strong	Strong	Normal	Low or none
	AV	Very high	High	Normal	Low or none
	FCA	Very often	Often	Normal	Low or none
Economy	OV	Very high	High	Normal	Low or none
	IOT	Very large	Big	Normal	Low or none
History	CHE	More than 5 times	2 to 5 times	1 or 2 times	None
	BA	More than 100 years	50 to 100 years	20 to 50 years	Less than 20 years
Society	PS	Very high	High	Normal	Low or none
	SI	Very large	Big	Normal	Low or none

Through objective data, we applied EWM to our various dimensions to obtain the weights of each positive and negative indicator, as shown in Table 3:

Table.3. the Weights of each Indicator

Object	Indicator	Weight	Object	Indicator	Weight
Culture	CI	0.3102	History	CHE	0.3219
	AV	0.4225		BA	0.6781
	FCA	0.2673		PS	0.4282
Economy	OV	0.2379	Society	SI	0.5718
	IOT	0.4764			

For the weights of these four first-level indicators, we use the Analytic Hierarchy Process (AHP) to get their values [12-13]. By investigating and constructing the matrix, we get the weights of four first-level indicators:

$$\delta = (0.43774, 0.12745, 0.17077, 0.26404) \quad (17)$$

Next, perform a consistency check:

Table.4. Consistency Test Result

Maximum	Characteristic Root	CI value	RI value	CR value	Result
4.094		0.031	0.882	0.036	Pass

The calculation results of the AHP show that the maximum feature root is 4.094, and the corresponding RI value is 0.882 according to the RI table, so $CR=CI/RI=0.036<0.1$, passing the consistency test.

Finally, Q_p is:

$$Q_p = \delta_1 \cdot Score_{Cul} + \delta_2 \cdot Score_{Eco} + \delta_3 \cdot Score_{His} + \delta_4 \cdot Score_{Soc} \quad (18)$$

3.3. Calculating results

The landmark we chose to apply was St. Mark's Basilica in the heart of Venice. Its special geographical location, vulnerable to floods, and the region has a long history and rich culture, so it was chosen here. According to the calculation of the possible maximum loss, the PML of 2025 to

2027 in Venice are 7.56, 9.58, and 11.44 billion dollars respectively. We collected the regional GDP , estimated maintenance costs, and resident population of Ven-ice in recent ten years, and carried out a simple linear fitting. Because the year is relatively recent, we assume that Q_p and K are constant.

Table.5. Data

Year	PML	GDP per Capita	Population	Qn	Qp
2025	7.56	41023	300127	452.23	
2026	9.58	41479	312874	481.94	7
2027	7.84	42018	321849	492.10	

The calculation shows that V in this region is 0.5527, 0.6681, and 0.5244 in the next three years. So we recommend hardening. Through the network survey, we found that our results are consistent with the measures being taken by the local government, which proves the effectiveness of our model.

4. Conclusions and Outlooks

Many landmark buildings have high historical or economic value, and it is important to assess the value of these buildings and develop conservation plans. To evaluate the value of the building, we first established the POT model to evaluate the risk of the building location. Then, based on the EWM-AHP method, we selected the first-level indicators and the second-level indicators to establish the value evaluation model of the building and used the logic function to establish the protection model through data fitting. According to the comprehensive analysis of the risk assessment and the value assessment of the building, the building protection measures are divided into three types: unprotected, reinforced, and relocated. Based on our model, we can assess the value of buildings in an area and determine what protection measures should be taken to protect them.

Through statistical analysis of the data, we found that with the increasingly severe environment, the frequency of extreme weather disasters increased very fast. In the public mind, extreme weather disasters are only reflected in economic losses, but in reality, the impact of extreme weather disasters is far beyond people's awareness. In order to prevent the destruction of our precious property, it becomes more important to predict and prevent the risk of disasters. Through our building value assessment and protection model, we can help people identify the value of buildings and get corresponding protection measures. Moreover, our model has high scalability and practical value. For example, when the specific use location is different, more constraints or more specific protection measures can be considered to achieve better results. This study applies the entropy weight method and the analytic hierarchy process. The method adopted has certain subjectivity, and there is room for further improvement in the future.

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