Forecast the Building Insurance Program Based on Grey Predictions and TOPSIS

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Abstract. The increasing frequency of extreme weather events around the world has had a significant impact on whether insurers continue to undertake projects related to buildings and the protection of architectural heritage. By building a grey forecasting model, this paper forecast the earnings of two national insurers, China, and the United States. By 2027, the earnings of the United States insurers will increase to 380 million dollars, and the earnings of Chinese insurers will increase to 106 million dollars. In addition, the technique for order preference by similarity to ideal solution (TOPSIS) model was used to calculate the degree of protection of the building, and the degree of protection of the building was divided into five levels according to the value of PT, and the protection suggestions were given respectively. The conclusions drawn in this article will help insurers whether to continue to underwrite in areas where extreme weather is frequent. At the same time, it provides new ideas for how to protect architectural relics in areas with frequent extreme weather.

Keywords: Extreme Weather Events, Grey Predictive Model, TOPSIS Model, Underwriting of Insurance Company, Conservation of Architectural Relics.

1. Introduction

Across the globe, extreme weather is becoming more frequent, having a significant impact on the real estate industry. Property insurance will cover most of the losses caused by extreme weather, and the high risk of extreme weather also means more expensive insurance costs, and insurance companies may even refuse to cover the high risk of extreme weather. However, the cost of property insurance has increased year by year, and the global average insurance protection gap has reached 57%.

Landmarks in areas with frequent extreme weather are vulnerable to damage, such as the Cape Hartres Lighthouse on the east coast of North Carolina in the United States, which was relocated inland in 1999 after the government moved inland due to the coastline [1]. There are many similar cases, and how to assess the extent to which buildings need to be protected under extreme weather and make recommendations for protection according to the type of risk have become important issues. An important consideration in insurance risk management is the impact of climate change, and as the impact of extreme weather intensifies, research on risk assessment of extreme weather events has made some progress. Statistical and machine learning methods were used to study climate risk assessment models for agricultural and household insurance [2]. Radar detection is used to predict the risk of extreme weather events in the region [3]. A high-resolution wind disaster risk database can be established using higher-resolution loss data to provide a solid foundation for risk assessment [4].

In addition, many studies have been conducted on the sustainable development of the insurance industry during extreme weather, such as the establishment of partnerships in reducing the risk of extreme weather, the three pillars of extreme weather recovery, and the methodology for evaluating sustainable development performance [5-7]. During the study, many conclusions suggest that the insurance industry has gradually become an important aspect of reducing the impact of extreme weather events [8-11]. Although the above study explores the risk assessment under extreme weather, it also provides a macro explanation of the important role of the insurance industry and the current situation of insurance under climate change and extreme weather disasters. However, there is no clear method to quantify the extreme weather risk in a specific region, and the insurance policies of the

relevant insurance industry do not provide specific application and improvement methods based on the actual disaster situation in a specific region.

To solve these problems, this paper proposes a new scheme to quantify the risks underwritten by insurance companies in a certain region by using the disaster losses (including disaster area, economic losses, etc.) combined with the gray prediction model, and predicts the income of insurance companies. Among the many extreme weather insurance projects, we have selected the most severely affected architectural artifacts to build a model of building conservation. According to the danger degree of the building and the mobility of the building, a new scheme is proposed for the classification of the risk level of the building, to put forward targeted protection measures for the building under different hazard levels. The combination of the insurance model and the building protection model will provide a new solution for the protection of buildings in areas with frequent extreme weather.

2. Theoretical model

2.1. Grey predictive model

Grey prediction is the prediction of systems that contain both known and uncertain information, that is, the prediction of time-related gray processes that change within a certain range. In this model, we express the insurer's profit as the difference between earnings and compensation:

$$I_N(t) = I(t) - O(t) \tag{1}$$

where $I(t)$ the annual income of the insurance company; $O(t)$ is the annual compensation amount; $I_N(t)$ is the final net profit of each year. The following will use the gray prediction model to model the income and compensation amount of the insurance company. We have collected data on benefits and compensation amounts from 2000 to 2023:

$$I^{(0)} = \left\{I^{(0)}(1), I^{(0)}(2), I^{(0)}(3), \dots, I^{(0)}(t)\right\} \tag{2}$$

$$O^{(0)} = \left\{O^{(0)}(1), O^{(0)}(2), O^{(0)}(3), \dots, O^{(0)}(t)\right\} \tag{3}$$

where $I^{(0)}(1)$、$O^{(0)}(1)$、$I_N^{(0)}(1)$ are for 2000. For the annual income of the insurance company, we will calculate the percentage of the annual insured amount in the national GDP $P_G(t)$:

$$I^{(0)}(t) + az^{(1)}(t) = b \tag{4}$$

$$z^{(1)}(T) = \delta I^{(1)}(T) + (1-\delta)I^{(1)}(T-1), T = 2,3,\dots \tag{5}$$

where G(t) is the national GDP over the years, -a is the development coefficient, b is the amount of ash, and δ=0.5. Finally, the gray differential equation of insurance company's income is as follows:

$$I^{(0)}(t) + az_0^{(0)}(t) = b \tag{6}$$

2.2. TOPSIS model

TOPSIS method is a commonly used comprehensive evaluation method, which can make full use of the information of the original data, and the result can accurately reflect the gap between the evaluation schemes. The basic process is to first unify the index types of the original data matrix and then conduct standardization processing to eliminate the impact of dimension and find the best and worst scheme in the limited scheme. Then, the distance between each evaluation object and the best scheme and the worst scheme is calculated respectively, and the relative proximity between each evaluation object and the best scheme is obtained, which is used as the basis for evaluating the pros and cons. The method has no strict restrictions on data distribution and sample content, and the data calculation is simple and easy.

For any building, which has its own cultural, historical, economic, and community significance, we define a building Hazard index, expressed by D_b. The higher the hazard index, the higher the level of protection it needs. According to the collected data, we divided the buildings into two categories: one

is non-removable buildings, including gardens, grottoes, etc., and the other is removable buildings, mainly museums and libraries. Below we set up conservation models for these two types of buildings respectively.

2.2.1. Immovable buildings

For non-relocatable buildings, we collected data on historic landmarks by state in the United States, including six aspects of cultural, historical, economic, community, scientific research, and weather significance. The data matrix is obtained $X_{n\times m} = [X_{ij}]$, and the matrix is $\widetilde{X_{n\times m}}$ after normalizing the indicators. First, the entropy weight method is used to calculate the weights of each index, which are respectively $(w_1, w_2, \cdots w_m)$, as shown in Table 1.

Table 1. Weights of each indicator

Index	History a	Culture b	Economy c	Community d	Scientific research e	Climate f
Weight	0.4562	0.0114	0.0146	0.0139	0.0263	0.4777

According to the weight, the final building risk index expression is:

$$D_d = 0.4562a + 0.0114b + 0.0146c + 0.0139d + 0.0263e + 0.4777f \tag{7}$$

According to the above formula, the risk index of a certain building can be obtained, and then the protection measures for buildings with different risk indexes can be obtained. Where the best and worst data in each index is selected, the best ideal point and the worst ideal point are obtained.

$$x^* = (x_1^*, x_2^*, \cdots x_m^*) \tag{8}$$

$$x_j^* = \max \widetilde{X_{\iota J}} \ (1 \le i \le m) \tag{9}$$

$$x^{**} = (x_1^{**}, x_2^{**}, \cdots x_m^{**}) \tag{10}$$

$$x_j^{**} = \max \widetilde{X_{\iota J}} \ (1 \le i \le m) \tag{11}$$

where x^* is optimal ideal point; x^{**} is worst ideal point. Then calculate the weighted distance between the evaluated object and the ideal point.

$$D_i^* = \sum_{j=1}^{m} w_j \left(\widetilde{x_{\iota J}} - x_j^*\right)^2 \tag{12}$$

$$D_i^{**} = \sum_{j=1}^{m} w_j \left(\widetilde{x_{\iota J}} - x_j^{**}\right)^2 \tag{13}$$

where D_i^* is the distance from the best advantage; D_i^{**} is distance from the nearest handicap; $\widetilde{x_{\iota J}}$ is the data of the normalized matrix. Finally, the synthetic evaluation function is substituted:

$$D_{bj}^* = \frac{D_i^{**}}{D_i^* + D_i^{**}} \tag{14}$$

A combination of building hazard index and ranking will be used to measure the degree to which a building needs to be protected:

$$PT = \beta D_d + (1 - \beta)R \tag{15}$$

where is PT the extent to which protection is required; β is the proportion of the building hazard; index R is the ranking of the building.

2.2.2. Transferable buildings

For the moveable buildings, we collected data from multiple museums in Beijing and selected the number of collections, exhibitions, educational activities, and visitors as reference indicators. The TOPSIS method is also used to calculate the degree to which a building is in danger. The weights of each indicator are shown in Table 2.

Table 2. Weights of each index in museums

Index	History a	Culture b	Economy c	Community d	Scientific research e	Climate f
Weight	0.4562	0.0114	0.0146	0.0139	0.0263	0.4777

Finally, the same calculation method as that of non-removable buildings is used to obtain the PT value of the degree of protection required for removable buildings.

3. Results and analysis

3.1. Grey prediction model - insurance forecasting

We forecast the income, compensation, and net income of insurance company respectively by using grey forecasting model. The insurance prediction model is applied to two different countries, the United States and China. The grey differential equations of the earnings of Chinese and American insurance companies are respectively:

$$I_{China}^{(0)}(t) - 0.083757 z_0^{(0)}(t) = 0.34671 \tag{16}$$

$$I_{USA}^{(0)}(t) - 0.05369 z_0^{(0)}(t) = 1.726 \tag{17}$$

The compensation model of insurance company also uses grey prediction. Due to the increasing frequency of extreme weather events, the insurance company will further increase the compensation related to natural disasters, which is the risk that the insurance company will bear. The damage of a natural disaster to a certain area is usually measured by the spread of the disaster, so we choose to determine the size of the compensation by the product of the damage area of the natural disaster to the area and the compensation per unit area. We have made relevant prediction on the damaged area, and the prediction equation is:

$$O(t) = S(t) \times I_d \tag{18}$$

where $S(t)$ is the damage area, I_d is the compensation per unit area and $O(t)$ is the compensation of the insurance company. The gray differential equation of the damaged area is obtained:

$$S^{(0)}(t) + c z_1^{(0)}(t) = d \tag{19}$$

Then, the degree of fitting between the results obtained by GM (1,1) model and the original data is checked by the mean relative residual and the mean grade ratio deviation. The calculated average relative residual and average stage ratio deviation are about 0.1, so it can be considered that this gray differential equation fits the original data very well. Based on the prediction equations of the earnings and compensation of insurance companies in the two countries, we forecast the earnings of Chinese and American insurance companies in the next five years respectively.

As shown in Figures 1 (a) and (b), the earnings of insurance companies in China and the United States will continue to increase over the next five years. By 2027, the income of China's insurance industry will increase to 107 billion dollars, and that of the US insurance industry will increase to nearly 3.8 billion dollars, which is more in line with the future economic development direction of the two countries. As can be seen from Figure 1 (c), the insurance company's compensation will show a decreasing trend in the next five years and will decrease to about 0.025 billion dollars by 2027. Although the probability of extreme weather has increased in recent years, there is still much

uncertainty about whether it will occur in the future. This forecast is an average, and if extreme weather was widespread each year, it would be an anomaly that would deviate significantly from reality.

As shown in Figure 1 (d), the relative residuals and grade ratio deviations in 2017 are large, and the fitting effect is not good. This is due to the impact of hurricanes Katrina, Wilma, and Rita on the United States in 2017. This was a record year for damage in the United States, so the prediction model was wrong to predict such anomalies. However, the occurrence of extreme weather in the United States has stabilized after 2019, so it can continue to predict future conditions. By 2027, the U.S. insurance industry will pay out 24.8 million dollars, which is due to the increase in domestic insurance penetration and the increase in the probability of extreme weather.

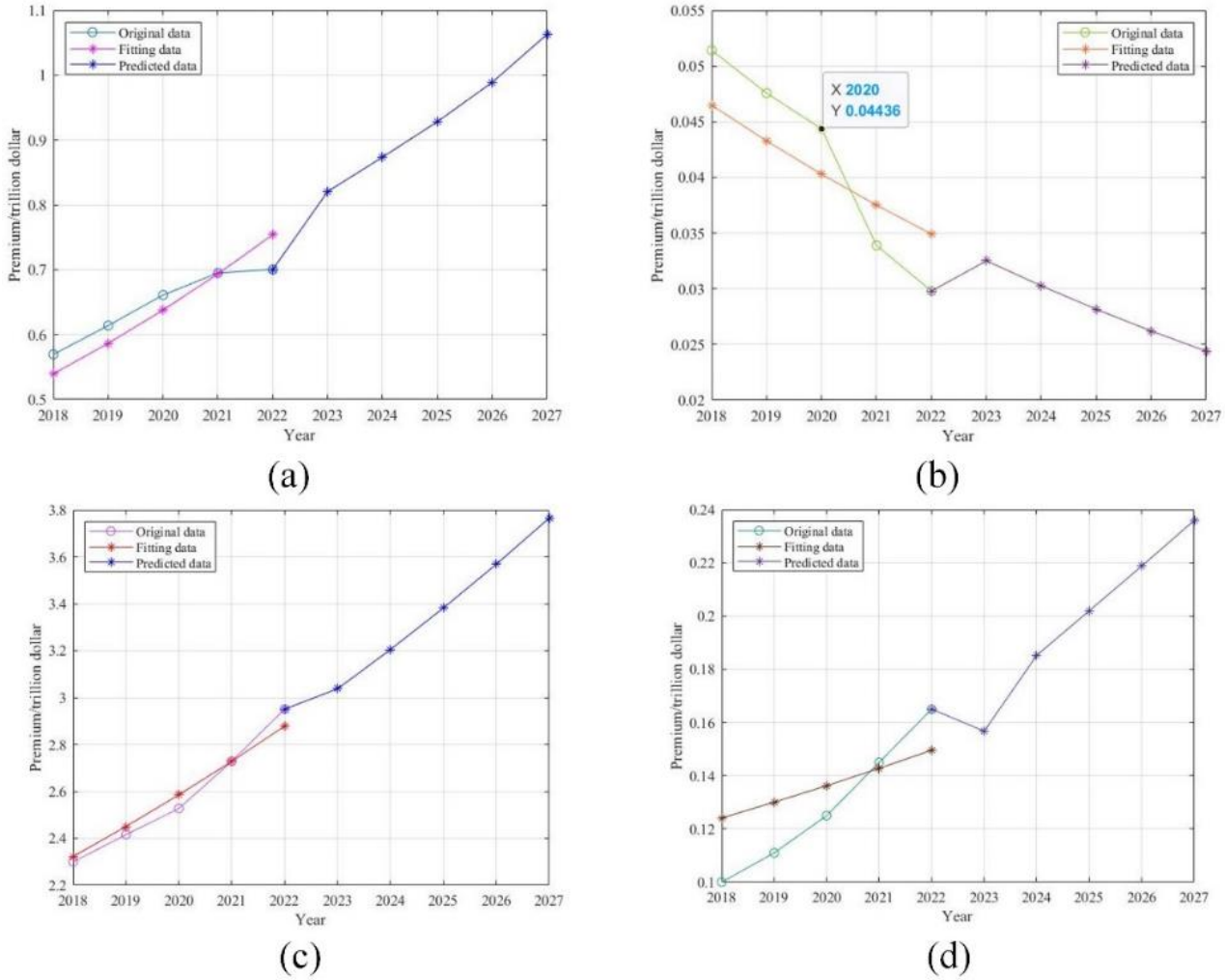


Figure 1. Forecast revenue and compensation of U.S. and Chinese insurance companies: (a) Forecast revenue of Chinese insurance companies; (b) Forecast revenue of the United States's insurance companies; (c) Prediction of compensation for Chinese insurance companies; (d) Prediction of compensation for the United States's insurance companies.

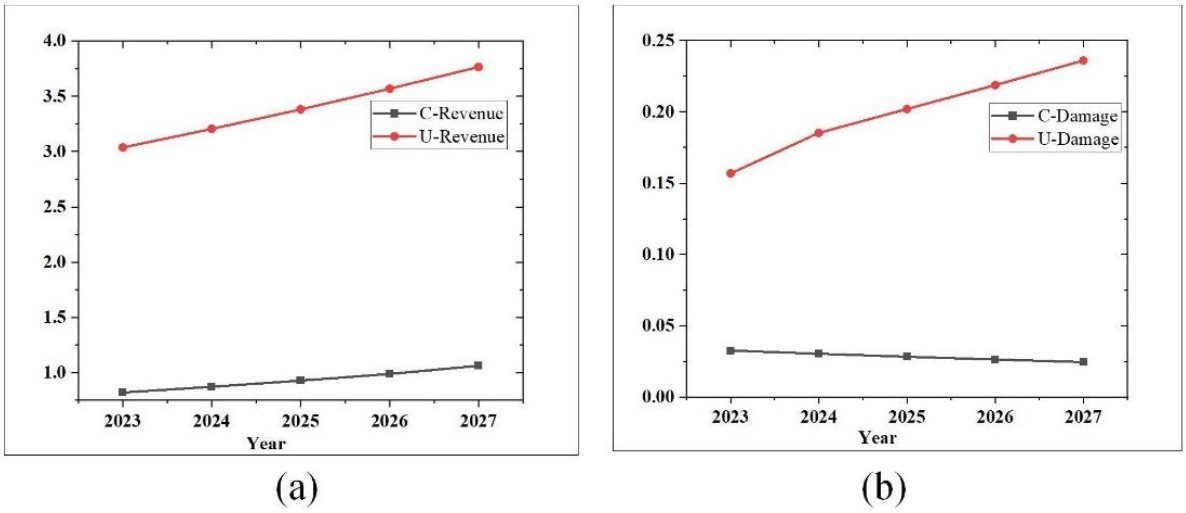


Figure 2. (a)Revenue forecasts for the insurance industry in China and the U.S; (b) Forecasts for compensation in the insurance industry in China and the United States

Subtracting the projected benefits and compensation yields the net benefits of the insurance sectors in the two countries, and Figure 2 shows the projected earnings and compensation for the insurance sectors in the two countries over the five-year period from 2023 to 2027. As can be seen from Figure 2, the earnings of the insurance industry in the two countries will continue to increase in the future. The amount of compensation will gradually decrease in the United States and increase in China, but it is still very different from the income, so the net income will show an increasing trend. This is in line with the profit margins of the insurance industry, which are declining but will continue to increase net profit due to the continuous increase in total revenue. At the same time, due to the release of local government policies and the continuous improvement of the ecological environment, it will also affect the change of the insurance company's compensation amount.

3.2. TOPSIS model -- Architectural heritage protection model

3.2.1. For non-removable buildings

Through the TOPSIS model, the degree of protection of buildings in the United States is analyzed, and specific protection recommendations are given for different situations. Finally, the degree of protection of each building is obtained, PT and ranking. Buildings are classified into 5 hazard classes as shown in Table 3 based on the PT score.

Table 3. Classification of building danger levels

Level	Non-reportable building PT score	Reportable building PT score
In the greatest danger	more than 460	more than 10000
In greater danger	450-460	5000-10000
In great danger	440-450	1000-5000
In lesser danger	425-440	300-1000
In very little danger	less than 425	less than 300

3.2.2. For portable buildings

For the moveable buildings, we collected data from multiple museums in Beijing, China, and selected the number of collections, exhibitions, educational activities, and attendance as reference indicators. The TOPSIS method is also used to calculate the degree to which a building is in danger. The weights of each index are 0.3347, 0.0977, 0.3573 and 0.2102. Then, by calculating the final PT value and ranking of the museum, we also divided it into 5 kinds of protection levels, as shown in Table 3.

When a building's PT score is greater than 460 or 10,000, it indicates that the building is in great danger and needs a high level of protection. Usually, such buildings have a long history, and due to their early construction time, the protection measures taken should be properly planned. At the same time, the protection strength will decrease with the decrease of PT, and the measures taken should also be adapted to local conditions.

4. Conclusions

In conclusion, this paper establishes a grey prediction model for insurance companies' returns and a conservation model for architectural artifacts. In areas with frequent extreme weather, whether insurance companies continue to undertake projects related to the protection of architectural heritage is mainly related to the local economy, society, and ecology. For economically developed areas, although extreme weather is frequent, it can continue to be covered. For economically underdeveloped areas, the way of underwriting should be changed. Through the TOPSIS model, this paper calculated the degree of protection of the building, divided the danger of the building into five levels, and gave different protection suggestions for the removable and non-removable buildings. Due to the sudden occurrence of extreme weather, which resulted in a large amount of data missing, our model still does not match the reality, and there are still areas for improvement. For areas with frequent extreme weather events, a new solution will be derived by combining insurance models and protection models.

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