Problem Chosen	2024 MCM/ICM Summary Sheet	Team Control Number
E		#2403378

Weather Changes Like the Weather Itself

Summary

Extreme weather increasingly alarms property owners and insurance companies due to its catastrophic impacts. This paper introduces a specialized model for evaluating and guiding decisions for insurance companies, real estate, and cultural community buildings affected by extreme weather events.

In task 1, the first goal is to establish a weather prediction model. This report obtained the weather data through NOAA then considering the seasonality of regional extreme weather **the SARIMA model** was applied to predict. Our second goal is to develop an risk assessment model. This paper collects 6 kinds of weather data and uses **the Entropy Weight Method** to obtain the weights of different disasters and then evaluate regional risk factors. Our third goal is to establish a **premium model**. We consider the profit level function and introduce the adjust factor σ of combining regional indicators. Through σ the region is divided into high, medium, and low premiums. decide whether to accept the bill. Then this report selects Portland and Bordeaux as cases to reflect the task 1 model.

In task 2, we firstly built an estate location model. This article grids the community and then introduces the home purchase confidence parameter TL, which reflects the quality of the surrounding buildings and then relates to the indicators of the **GDP level** and **economic growth rate**. Using the **Analytic Hierarchy Process(AHP)** to get the weights of these three indicators. ω**= [0.5816, 0.1095, 0.3090]**. Calculate the score for each point of the grid and render the map. Select dark areas to build estate. Secondly, build an estate premium model. Based on the first premium model, this report adds a house risk coefficient DR to the profit function to represent the house's resistance to disasters. At the same time, TL is also included in the model. New high, medium, and low premiums are divided for new district development decision-making.

In task 3, we firstly established a landmark protection model. The report firstly constructs four evaluation indicators CI, EI, HI, MI to evaluate the **value** of a landmark. The second step is to construct a **multi-layer AHP model** to include the two program layers of ex-situ and in-situ conservation in the evaluation together with the criterion layer. The weights of the four indicators ω**= [0.33, 0.47, 0.07, 0.13]**, we also obtained the weight of the program layer corresponding to each indicator. In the third step, the score is obtained through double-weight calculation as the result of the protection model.

In task 4, we aimed to build a landmark value model. We first selects Castle Clinton in New York as a cultural landmark, integrates the premium model and conservation model, and brings it into the premium model obtained that I **= 0.42** as the medium premium area. Then it uses **Cost-Benefit Analysis (CBA)** to display maintenance costs into the profit value of the first question. Level function as the cost of Fort Clinton. The EWM is used to linearly combine the cultural value, CI, EI, and HI in the protection model as benefit income. Finally, the value is calculated to obtain a graph of Clinton castle's value changing over time. Based on the results, he wrote letter to community leaders with plans, timelines and cost recommendations.

This report also conducted a **sensitivity analysis** on the model and concluded that the impact of the adjustment factor DR on the value model is negligible under a **10%** Oscillation amplitude.

This report finished four tasks by building **targeted models** for future insurance companies, community estate and landmark buildings based on extreme weather. Combining economics with multiple indicators and forecasting models to produce high-quality models.

KeyWords: SARIMA; Premium model; ESW; AHP; CEHM-Protection Model; K-Means clustering

Contents

1 Introduction

1.1 Background

"North Atlantic hurricanes have increased in intensity, frequency, and duration since the early 1980s." stated Courtesy of NOAA on its website. Weather is a fundamentally chaotic system—even incredibly small disturbances can massively impact atmospheric conditions. According to Kraehnert et al.(2020), in recent years, such climate change has been expected to lead to more frequent and severe extreme weather conditions, including droughts, heatwaves, and intense rainfall (IPCC 2014; WMO 2020) [1,2,3]. This escalating risk leads to a spiral in premiums for insurance coverage, posing a significant threat to property owners and the insurance sector around the world, albeit in different manners.

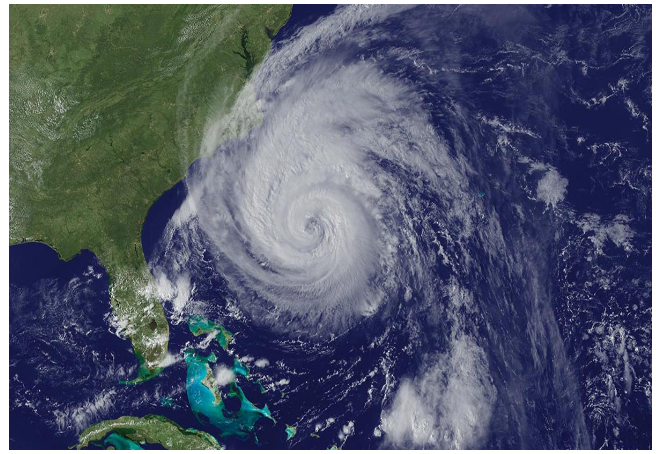


Figure 1: North Atlantic hurricanes

Confronted with the dilemma of balancing profitability and owner affordability, the insurance sector urgently needs to assess the risk of underwriting policies in regions experiencing an increase in extreme weather events. Consequently, it is imperative for a model that aids insurance companies in evaluating such risks not only to facilitate decision-making but also to have implications for other sectors like real estate and community insurance coverage within a specific area.

1.2 Problem Restatement

Based on the background information and identified restrictions, we need to implement several measures to address the following issues:

- **Problem 1 Restatement**: Develop a model to evaluate the challenges of risk management and maintaining long-term sustainability for insurance companies in the context of more frequent and severe extreme weather events caused by climate change.
- **Problem 2 Restatement**: Adjust the insurance model to assess where, how, and whether construction should take place in certain locations to ensure future properties are resilient and purposefully built.
- **Problem 3 Restatement**:Develop a protection model to help identify measures for protecting properties within a community that have cultural, historical, economic, or communal significance.
- **Problem 4 Restatement**:Apply the protection model to assess the value of a specific historical landmark, considering the risks of extreme weather events, and draft a proposal letter for the community, outlining the future plans, timeline, and cost suggestions for preserving the precious landmark.

1.3 Our-Work

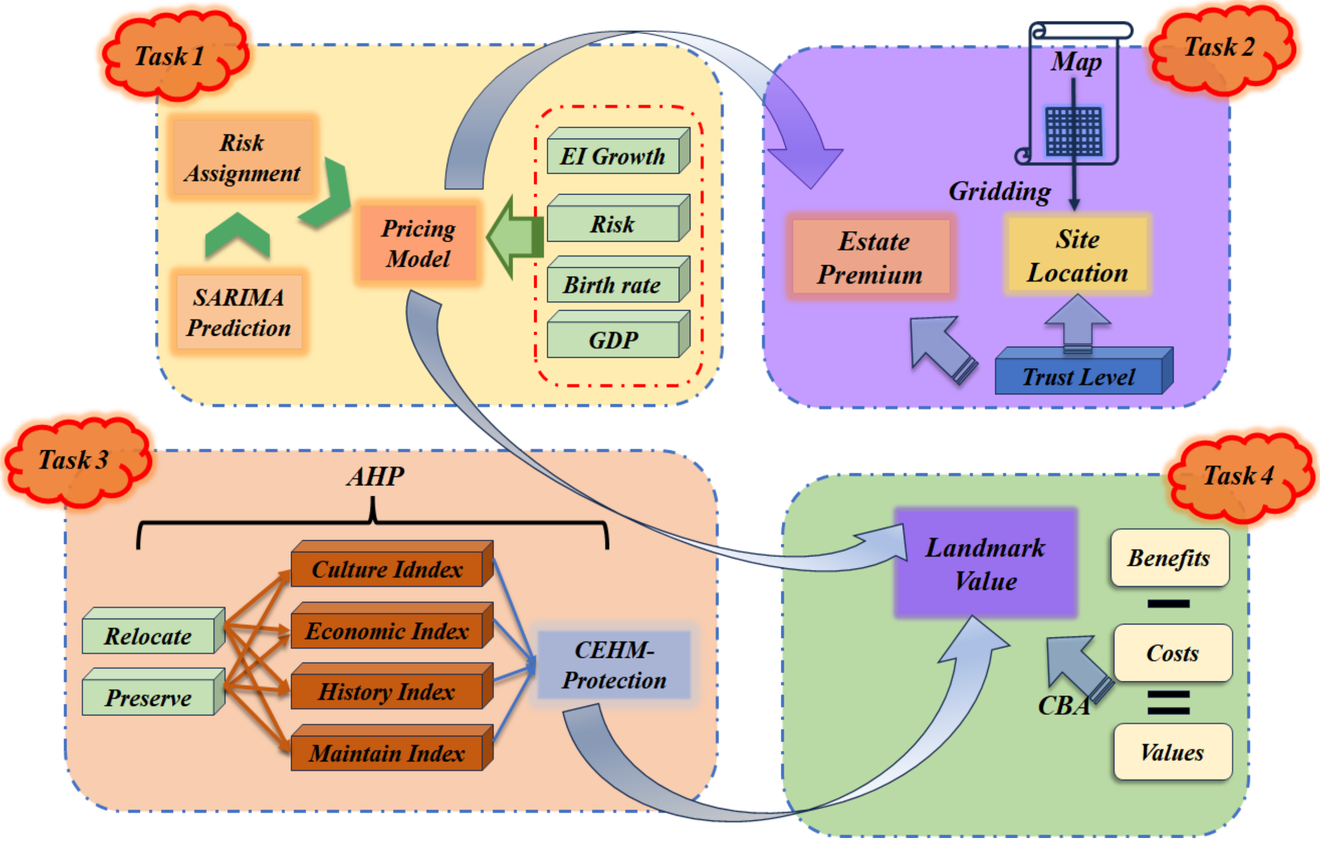


Figure 2: Our Work Mind Map

2 Assumptions and Justifications

To simplify the problem, we make the following basic assumptions, each of which is properly justified

- **Assumption 1:** This research only looks at damages from severe weather incidents.
  - *Explanations:* This assumption allows us to isolate the financial impact of extreme weather events from other types of insurance claims. It simplifies the model by focusing on quantifiable and significant events that have direct financial repercussions on the insurance industry.
- **Assumption 2:** Considering global variations in resilience and unpredictability of severe weather, this research treats the damage to particular regions from such weather as a fixed value.
  - *Explanations:* Assuming constant damage values facilitates a uniform approach to risk assessment across different regions. It also simplifies the model by avoiding the need for detailed, localized data, which may not be consistently available.
- **Assumption 3:** Given economics' intricate and varied nature, this research regards the return coefficient i to be consistent and unvarying, linking it to the world's inflation rate in its application.

- *Explanations:* This assumption stabilizes one of the variables affecting insurance payouts and premiums, allowing us to focus on the variability of other factors. It provides a baseline for comparing the real value of future payments against present costs.

- **Assumption 4:** Despite currency devaluation issues, insurers should still offer payouts at least equal to the customer's paid premiums to remain competitive.
  - *Explanations:* This assumption ensures the economic viability and competitive nature of insurance offerings. It reflects the principle that insurance should provide net positive value to customers after considering currency devaluation.

3 Notation

Table 1 shows all the in the paper.

Table 1: Table of Notations

Symbol	Description
W	Gross income from this insurance scheme.
m	Indemnity paid to a client.
N	GDP level.
r	Growth rate.
σ	Adjustment factor tied to four variables.
BP	Base fee of the insurance.
I	Extreme weather risk factor in section 5.2.
p	Level of profitability (as a percentage).
DC	Degree of convenience.
TL	Trust Level.
DR	Disaster Resistant Housing System.

4 Data Collection

The data we used mainly include records of extreme weather, rainfall data, temperature data, GDP data, population data.,etc. The data sources are summarized in Table 2.

Table 2: Data Source Collection

Database Names	**Database Websites**
NOAA	National Weather Service
NASA	`https://www.nightlights.io/`
Union of Concerned Scientists	`https://ucsusa.org`
OpenStreetMap	`https://opentiles.org`
Google Scholar	`https://scholar.google.com/`

5 Problem 1

5.1 Weather Forecasting Model Based on Seasonal ARIMA

In regions where extreme weather events are becoming more frequent, accurately predicting these events is crucial for disaster prevention and control. In this section, we will delve into an analysis of Florida's climate characteristics and build a precipitation forecast model based on historical weather data for the area. By evaluating the frequency and severity of various types of natural disasters, we have identified rainfall as the most common indicator of natural disasters. Following this discovery, we will employ time series analysis techniques to predict future precipitation trends, providing data support for disaster prevention and resource allocation.

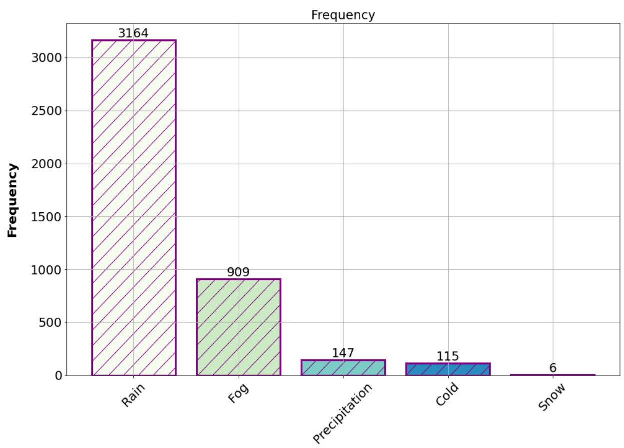


Figure 3: Frequency of Weather Conditions

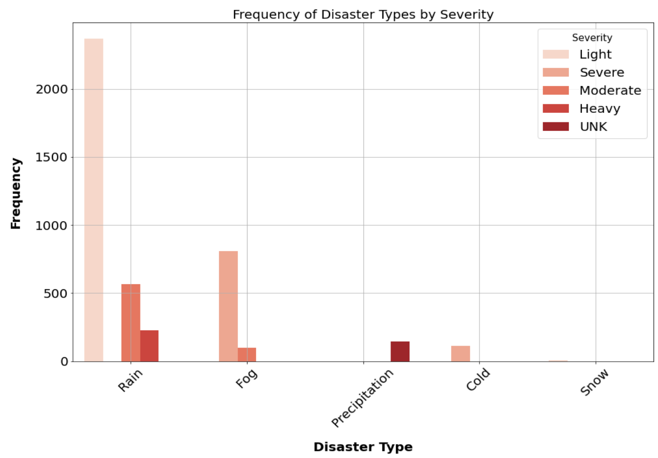


Figure 4: Frequency of Disasters by Severity

These two images display histograms of the frequency of different types of natural disasters as well as their frequency classified by severity. It can be inferred that in Florida, rainfall is the most common natural disaster event and can be represented by rainfall amounts and forecasts to depict the occurrence of natural disasters.

This chart shows the average monthly rainfall in a region (presumed to be Florida) from September 2015 to January 2023. Blue dots indicate the monthly average rainfall, measured in inches, linked by a red line to illustrate the trend over time. The data reveals fluctuations—some months show rainfall exceeding 0.4 inches, while others register less than 0.1 inches. Despite these variations, there's no evident trend of increase or decrease in rainfall, suggesting possible seasonal influences. Yet, the graph lacks a clear seasonal pattern, as it doesn't consistently repeat the same rainfall trends annually.

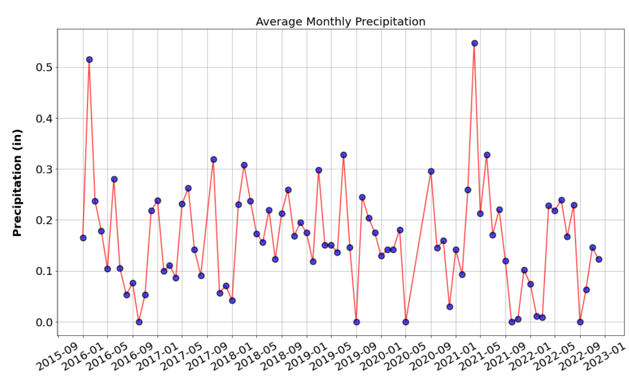


Figure 5: Average Monthly Precipitation

To predict Florida's rainfall patterns for the next two years, we used the Seasonal Autoregressive Integrated Moving Average (SARIMA) model, ideal for forecasting seasonal time series data. After training the model with 2015-2023 data, we forecasted the monthly average rainfall for the coming two years, indicating future rainfall trends.

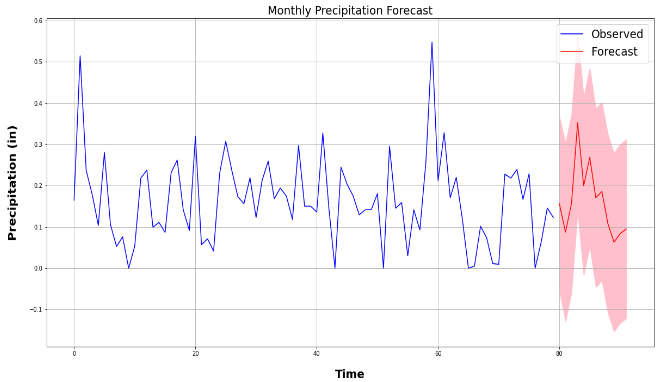


Figure 6: Auto and Partial-auto Correlation

The chart on the left displays the observed and predicted values of monthly precipitation. The blue line represents the actual observed precipitation data, whereas the red line indicates the predicted values of precipitation. The red shaded area stands for the uncertainty or confidence interval of the prediction. The time axis (horizontal) represents the sequence of observation and prediction points in time, while the precipitation (vertical) is measured in inches. It can be seen from the chart that, in the prediction area (red shade), the predicted values sometimes are higher and sometimes lower than the actual observed values, demonstrating the range of variation in the predictions.

The SARIMA model results present a statistical analysis of the time series data, including estimated coefficients for autoregressive terms, seasonal autoregressive terms, and seasonal moving average terms, along with their standard errors, t-values, and P-values. The variance of the model (`sigma2`) is quite low, indicating minimal fluctuation in the error terms. Key statistics are as follows:

- Log Likelihood: 43.663, indicating the goodness of fit of the model to the data.
- AIC (Akaike Information Criterion): -79.327, used for model selection, with smaller values indicating a better model.
- BIC (Bayesian Information Criterion): -71.297, similar to AIC but with a higher penalty for model complexity.
- HQIC (Hannan-Quinn Information Criterion): -76.222, a model selection criterion that lies between AIC and BIC.

The P-values for the Ljung-Box test and the Jarque-Bera test indicate the randomness and normality of the model residuals. These results suggest that the chosen model may fit the data quite well.

5.2 Risk Assessment Model

5.2.1 Indicator Selection and Poisson Distribution Applications

We aim to evaluate natural disaster risks in eight Southeastern U.S. cities by analyzing six key extreme weather conditions: rain, fog, cold, hail, snow, and storms, crucial for assessing their impact on urban life and infrastructure.

By calculating the annual frequencies of these events, we establish their average occurrence rates. These rates serve as parameters for the Poisson distribution, enabling us to predict the probability of each event occurring within the next year. This method, based on statistical analysis and the Poisson distribution, lays the groundwork for further city-specific risk assessments using the entropy weighting method, offering an objective framework to quantify natural disaster risks.

$$P(X \geq 1) = 1 - P(X = 0) = 1 - e^{-\lambda} \tag{1}$$

This probability value will provide our risk assessment model with a single risk measure for each type of extreme climate condition.

Table 3: Annual Probability of Extreme Weather Event ($X > 0$)

State	Rain	Fog	Cold	Hail	Snow	Storm
Virginia	1.00	1.00	0.99	0.43	1.00	0.99
Florida	1.00	1.00	1.00	0.00	0.57	0.00
Georgia	1.00	1.00	0.99	0.00	0.13	0.43
North_Carolina	1.00	1.00	0.13	0.92	1.00	0.79
South_Carolina	0.00	1.00	1.00	0.00	0.00	0.24
Alabama	1.00	1.00	1.00	0.00	0.24	0.68
Mississippi	0.00	1.00	1.00	0.00	0.51	0.00
Louisiana	1.00	1.00	0.99	0.00	0.86	0.57

This table provides the probabilities of at least one occurrence of various extreme weather events within a year for eight states, based on Poisson distribution parameters derived from historical data.

5.2.2 Risk Index Scoring Based on Entropy Weight Method

After calculating extreme climatic event probabilities using the Poisson distribution, we apply the entropy weight method to assign relative weights to different meteorological events for assessing natural disaster risk.

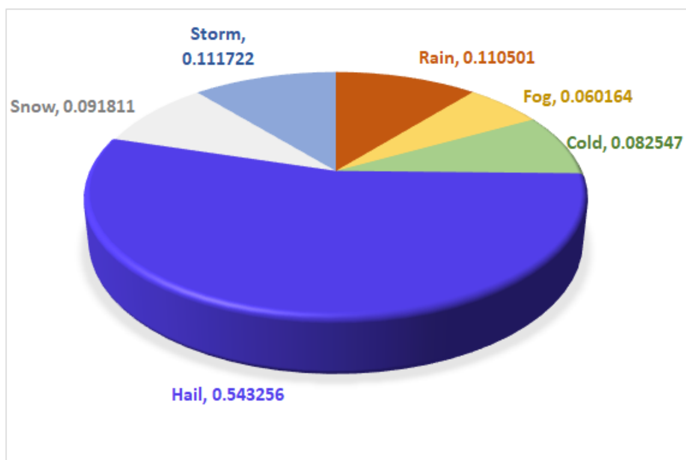


Figure 7: Auto and Partial-auto Correlation

The weight assigned to each index in the EWM calculation is determined by its information entropy, which reflects the degree of variability of the index. The higher the information entropy, the more significant the index is in the assessment. Thus, utilizing EWM to determine the weight of each index in the calculation of the index of light pollution is an objective approach.

After preprocessing the data, we obtained data for the last three years from the 8 regions. As these indicators are all positive, we standardized the data:

$$Y_{ij} = \frac{X_{ij} - min(X_{ij})}{max(X_{ij}) - min(X_{ij})} \tag{2}$$

where X_{ij} represents the original data of the i-th indicator value of the j-th grid, while $\min(X_{ij})$ and $\max(X_{ij})$ represents the minimum and maximum data in the i-th indicator of the $j - th$ grid

The information entropy can be obtained from Eq.3.

$$\begin{cases} P_{ij} = \dfrac{Y_{ij}}{\sum_{i=1}^{3} Y_i} \\ E_j = -\dfrac{1}{\ln n} \displaystyle\sum_{i=1}^{3} P_{ij} \ln P_{ij} \end{cases} \tag{3}$$

If $P_{ij} = 0$, plug (3) into (4):

$$\lim_{P_{ij} \to 0} P_{ij} \ln P_{ij} = 0 \tag{4}$$

Based on the information entropy E_j, the weight of each indicator could be calculated.

$$W_i = \frac{1 - E_i}{k - \sum E_i} \quad (i = 1, 2, 3) \tag{5}$$

This pie chart displays the weight distribution for different extreme weather events, highlighting hail events as having a notably higher weight compared to others. Using the entropy weight method to calculate these weights and combining them with occurrence probabilities, we've formulated a natural disaster risk index for cities. This index, by integrating event probability and significance, serves as an instrument to assess the specific natural disaster risks faced by cities.

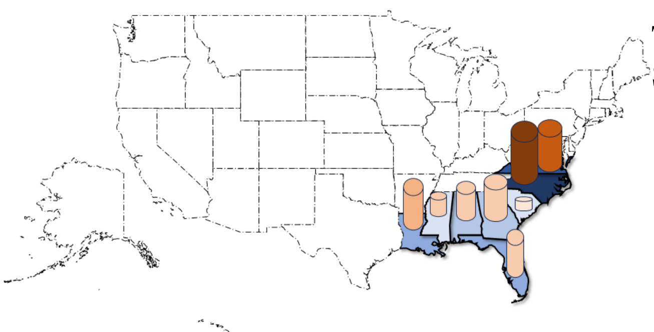


Figure 8: Extreme Weather Risk in the Southeastern United States

Table 9: Natural Disaster Risk Index for Selected States

State	Risk Index
Virginia	0.692930
Florida	0.306061
Georgia	0.314064
North_Carolina	0.863713
South_Carolina	0.110312
Alabama	0.352122
Mississippi	0.189577
Louisiana	0.396703

The table displays the natural disaster risk index for eight states; a higher index means a higher risk. North Carolina has the highest risk index of 0.863713, indicating greater potential for disasters. Conversely, South Carolina, with the lowest index of 0.110312, has a lower risk. The index ultimately contributes to a score for each city, representing its risk of facing major disasters over time.

5.3 Insurance Pricing Model

5.3.1 Model Construction

The increasing frequency of extreme weather events in recent years has led to exorbitant insurance claims. Therefore, global insurance companies need to develop a more reasonable premium pricing model for their extreme weather insurance offerings. This model should ensure profitability without alienating customers, thus promoting the sustainable development of both the economy and the insurance sector.

Given the gross profit rate calculation and the concept of compound interest present value, we developed a pricing function for extreme weather insurance:

$$W = DR(p, m, I, \sigma, i, BP_0) \tag{6}$$

The function DR is yet to be determined. To seek the functional form of DR, we make the following assumptions.

- **Sustainability of profitability level** p

  The profit level p is a function of time t, we require that its derivative and it itself always be positive when $t > 0$, which guarantees the profit sustainability of this extreme weather insurance.

- **Compound interest present value formula**

  Given the inflationary nature of money, we denote the inflation rate as i, taking the future value

$$BP = \frac{BP_0}{(1+i)^t}, \tag{7}$$

  which reflects the real monetary value BP of the underlying premium BP_0 after t years.

- **Rejection of proposals**

  Proposals are rejected under two scenarios:

  - **Firstly**, when t is excessively large, meaning the return on investment period is too long to reach the level of profitability.
  - **Secondly**, when $m < BP_0$, indicating that the base charge is higher than the payout, hence $\sigma < \frac{m}{BP_0}$.

- **Adjustment factor** σ

The adjustment factor σ, reflecting the premium level of the region, is a comprehensive determination based on extreme weather risk coefficient I, The local GDP level, economic growth rate and birth rate are calculated by using the method of entropy weight and then multiple regression. The value of σ falls within the interval $(0, \frac{m}{BP_0})$.

With comprehensive assumptions above, we define a charging model with a profit level p as follows:

$$p = \frac{\frac{BP_0 \cdot \sigma}{(1+i)^t} - m \cdot I}{\frac{BP_0}{(1+i)^t}} \tag{8}$$

Solving for m yields the relationship of the base premium to the profit level p:

$$m = \frac{(\sigma - p) \cdot BP_0}{I \cdot (1+i)^t} \tag{9}$$

with the condition that $m > BP_0$.

The formula reveals the crucial role of the adjustment factor σ in linking indemnity m, profitability p, and time t, given known values of inflation rate i, base premium BP_0, and risk coefficient I. Identifying the weights of σ's components is therefore essential.

The extreme weather insurance pricing strongly interacts with the local severe weather risk index, birth rate, economic growth rate, and GDP level [6]. We use the entropy weight method to assign weights to these factors based on gathered data, shown in the adjacent figure.

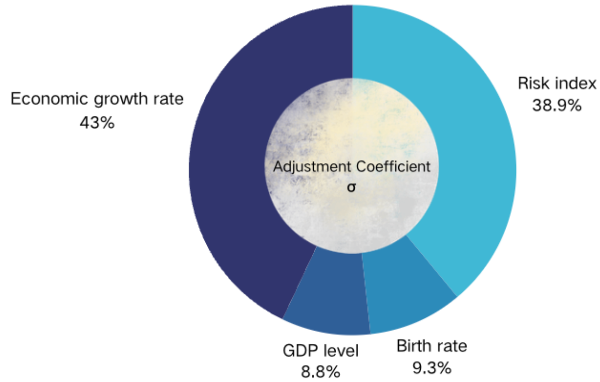


Figure 10: Weight Distribution of Adjustment Factor

For each city, we compute the sigma value by blending weights derived from the entropy weight method with relative indicators, and then scale these results to lie within [1,2] range for specific sigma values.

We calculated the sigma values for every city and used the elbow method on these figures, concluding from chart Fig.12 that the perfect cluster number is 3. Thus, we divided cities into high, medium, or low groups using K-Means clustering via sigma values, establishing cluster cores for each level.

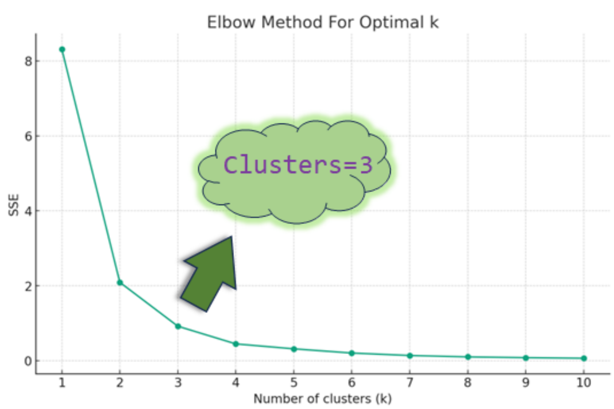


Figure 11: Elbow diagram

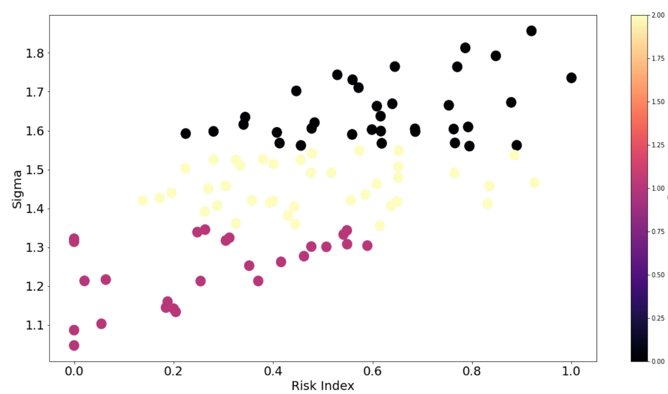


Figure 12: Indemnity Amount as a Function of Time and Risk Index

This Fig.13 is a scatter plot that illustrates the relationship between the risk index and the adjustment factor σ. The colors of the dots represent different clustering areas, which are divided into three separate premium intervals based on the value of σ.

Based on the graph, we can draw the following conclusions:

- When σ is between 1 to 1.2, the area is considered to be in **the low premium zone**.
- When σ ranges from 1.2 to 1.5, it falls within **the middle premium zone**.
- When σ is between 1.5 to 2.0 or above, it is classified into **the high premium zone**.

The coordinates of the clustering centroids are $(0.1312, 0.1523, 0.1825)$. These centroids may represent the average or the most typical risk index values for each premium zone.

Based on these clustering analysis results, insurance companies can determine different area's premium strategies according to the risk index and corresponding σ value. The low premium zone represents lower risk, while the high premium zone denotes higher risk. This approach facilitates a reasonable match between risk and premium.

Analyzing σ, we note the compound present value's critical impact on payout m and base premium BP_0 (set at \$500) over time t. The model illustrates this through two curves: the red curve for the base premium's depreciation due to compound interest, and the blue curve for the trend in insurance payouts, emphasizing the compound present value's essential role.

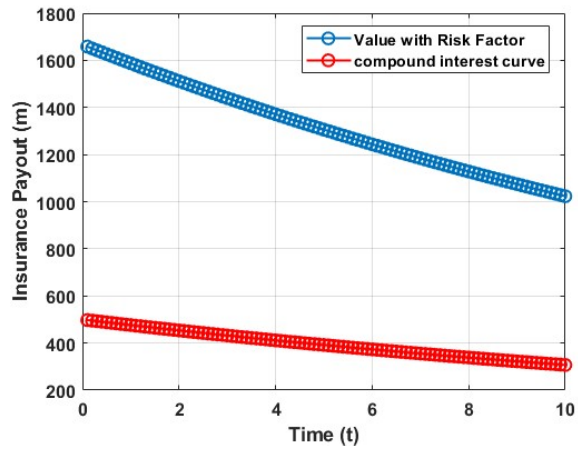


Figure 13: Inflation Impact on m

Having established a method for calculating σ, for regions with a stable risk index (assuming $I = 0.3$), we derive the compensation m as a function of profitability p and time t. We proceed under the assumption of a global inflation rate $i = 0.05$ and a base premium $BP_0 = 500$ dollars.

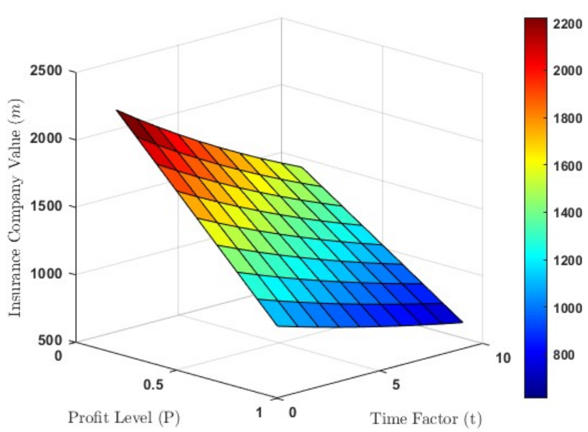


Figure 14: Compensation Relation Surface

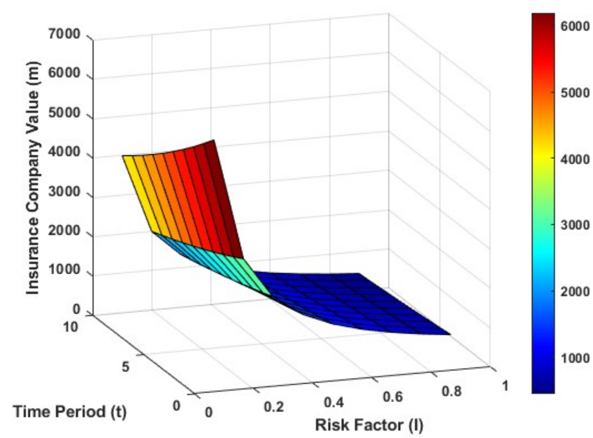


Figure 15: Indemnity Amount as a Function of Time and Risk Index

As shown in the figure above, with a risk coefficient of 0.3, the compensation m reduces as profitability p and time t increase. The surface plot below illustrates how m varies with t and the risk coefficient I, indicating m's high sensitivity to I. This highlights the significant impact of extreme weather risks on insurance profitability.

The following are the payment surfaces of low, medium and high risk zones.

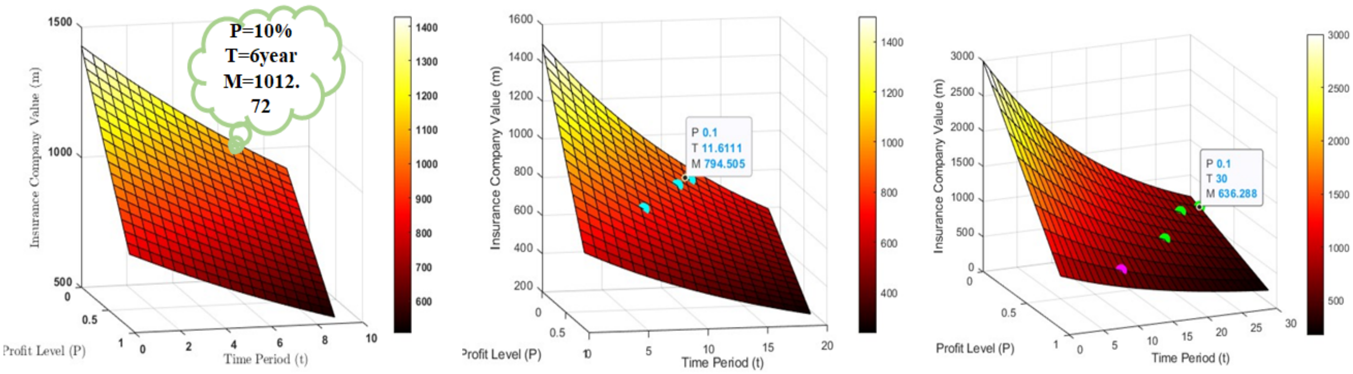


Figure 16: Payment Surfaces for Different Risk Zones

The conclusion of payout amounts corresponding to different profit rates can be summarized.

Table 4: Premium Plan Conclusions

Adjustment Factor Area	1.0–1.4	1.4–1.6	1.6–2.0
Risk Level I	(0%, 30%)	(30%, 60%)	(60%, 100%)
Premium Zone	Low	Medium	High
Optimal σ	1.3	1.5	1.8
P=10%	$M = 636, t < 30$	$M = 794, t < 12$	$M = 1013, t < 6$
P=20%	$M = 703, t < 26$	$M = 776, t < 11$	Rejection
P=50%	$M = 659, t < 20$	$M = 752, t < 6.3$	Rejection
P=80%	$M = 613, t < 10$	Rejection	Rejection

Based on our model, we explored how different risk zones affect the required claim payments and acceptable time spans to achieve specific profit margins. Our findings indicate:

- For a 10% profit margin, claim payments of \$636 over less than 30 years in low-risk zones, \$794 under 12 years for medium-risk, and \$1013 within 6 years for high-risk are feasible.
- Increasing the profit margin to 20%, low-risk zones should set claims at \$703 for under 26 years, medium-risk at \$776 for less than 11 years, and avoid high-risk zones due to high risk.
- With a 50% profit goal, \$659 for less than 20 years in low-risk, and \$752 for under 6.3 years in medium-risk zones are viable. High-risk coverage is not recommended.
- For an 80% profit, only \$613 for under 10 years in low-risk zones is advisable, with medium and high-risk zones being too risky for coverage.

This concise analysis shows the relationship between claim payments, return periods, and risk levels, guiding insurance firms in aligning profit objectives with risk management.

5.3.2 Model Demonstration

The preservation mode we established is fully scientific, universal and rigorous. Now, we will demonstrate our insurance model with two regions in the world with increasing extreme weather events in two different continents.The regions we choose are Portland in North America and Bordeaux in Europe.

Applying SARIMA model, it is found that the rainfall and snowfall in both places dominate the extreme weather, so the rainfall and snowfall predictions are selectively made, and the prediction chart is as follows.

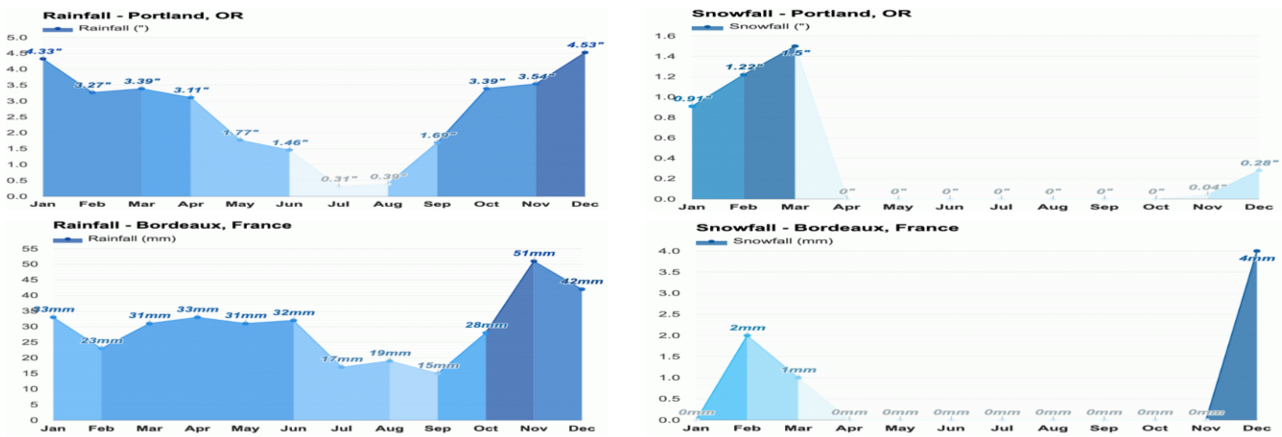


Figure 17: Rainfall and Snowfall Predictions

Then, we calculated the risk indices of the two places respectively through the risk index model of 5.2, which are 0.5501 (Portland) and 0.4522 (Bordeaux).

The compensation surface of compensation amount m with respect to profit rate p and time t is given by using the pricing model of 5.3, as shown in the figure below:

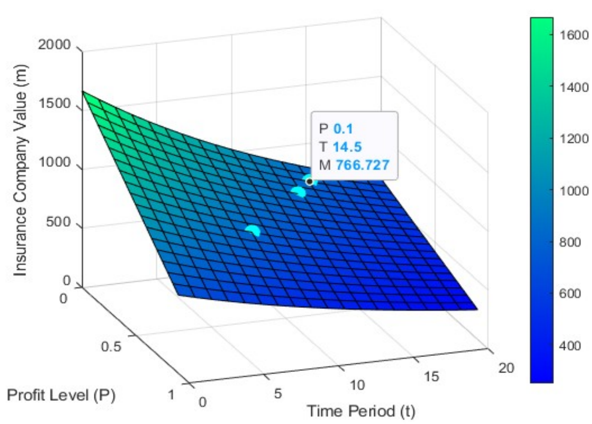


Figure 18: Compensation Relation Surface

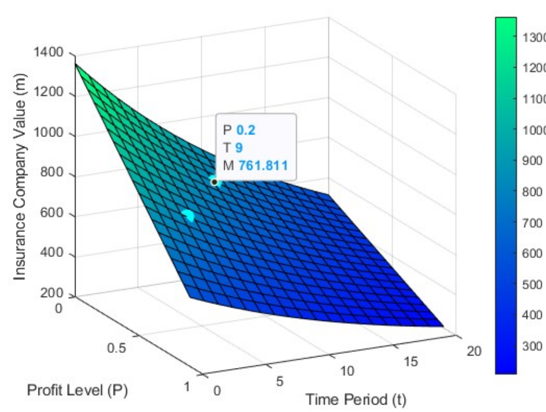


Figure 19: Indemnity Amount as a Function of Time and Risk Index

In summary, we present the insurance payout plans for Portland and Bordeaux.

Table 5: Insurance Payout Plans for Portland and Bordeaux

	Location	
Profitability Level	Portland	Bordeaux
P=10%	$M = 758, t < 14.5$, Mid-long term	$M = 764, t < 11.5$, Mid-long term
P=20%	$M = 753, t < 13$, Mid-short term	$M = 765, t < 9.4$, Mid-short term
P=50%	$M = 756, t < 7.8$, Short term	$M = 762, t < 3.84$, Short term
P=80%	Rejection	Rejection

6 Problem 2

6.1 Community Real Estate Site Selection Model

6.1.1 Human Development Index

The choice of housing location is mainly determined by the homebuyer's trust in the community, which varies spatially with two-dimensional positional changes and is actually about multiple influencing factors. To measure and assess the level of the homebuyer's trust, we consider its three features:GDP level, economic growth rate, Convenience level.

The convenience level includes aspects such as residential areas, education, healthcare, entertainment, etc., and can be characterized by different densities of real estate properties. DC is defined as(The REC here is defined as Real Estate Categories and Cv is defined as Coverage)

$$DC = \sum_{i=1}^{n} \text{REC} \times \text{Cv} \tag{10}$$

There for we need to combine the scores of the three subsystems of the standardized **Community Real Estate Site Selection Model**.The GDP level, economic growth rate, Convenience level were considered. Then we establish the initial Comparative Matrix.

$$M = (a_{ij})_{3\times 3}$$

The a_{ij} represents the relative importance of index i to index j. The development index can reflect a certain extent the hotness of people's attention at a specific time and can be used to circumvent the subjectivity of the hierarchical analysis method. We get the relative importance of each index in the matrix:

$$M_0 = \begin{bmatrix} 1 & 5 & 2 \\ 1/5 & 1 & 1/3 \\ 1/2 & 3 & 1 \end{bmatrix}$$

Therefore, ω = (0.5816,0.1095,0.3090) is taken as the weight vector among GDP level, economic growth rate, Convenience level.After the consistency test, we can complete the quantification of the homebuyer's trust level. Based on the weight vectors W, we can calculate the score of trust level in the Equation below.

$$\text{TL} = \omega_1 \times \text{GL} + \omega_2 \times \text{EGR} + \omega_3 \times \text{CV} \tag{11}$$

tl here stands for Trust Level.GL here stands for GDP level.EGR here stands for Economic growth rate.CV here stands for Convenience level.

The consistency of the judgment matrix in the Analytic Hierarchy Process (AHP) analysis is confirmed through a consistency check, yielding a Consistency Index (CI) of 0.0018 and a Consistency Ratio (CR) of 0.0036. With the CR value well below the acceptable threshold of 0.1, the matrix is deemed highly consistent and suitable for further decision-making analysis.

6.1.2 Render Score Layers

After successfully building the trust score model, we selected Long Beach and its downtown area as the application objects and deployed the trust score model in these two areas respectively. The following two images show the geographical locations of the Long Beach area and the downtown area.

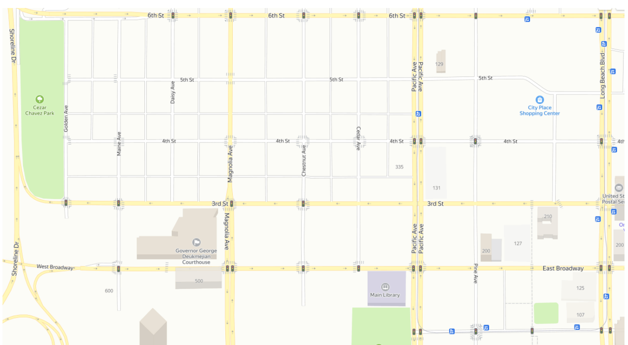


Figure 20: Downtown Map

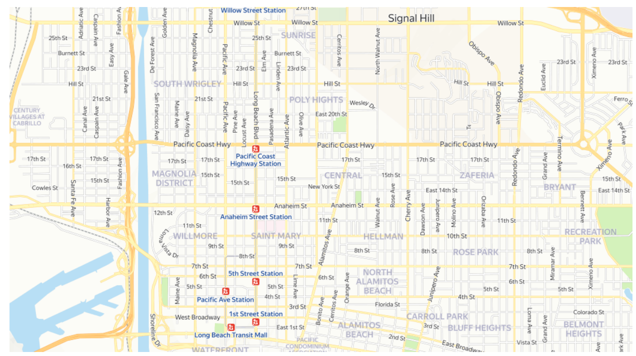


Figure 21: Long Beach Map

To implement the trust score model, we'll conduct a grid analysis on two maps, focusing on three key indicators per grid. This approach divides maps into uniform squares, enabling precise measurement and comparison of trust levels across regions.

Gridding involves refining spatial data across two dimensions, where each grid captures specific details through three indicators, such as population or geographical features [5]. These indicators' statistics are crucial for calculating each grid's trust score.

The strength of this method lies in its ability to standardize spatial data analysis. By avoiding random geographical divisions, it enhances the model's accuracy and utility.

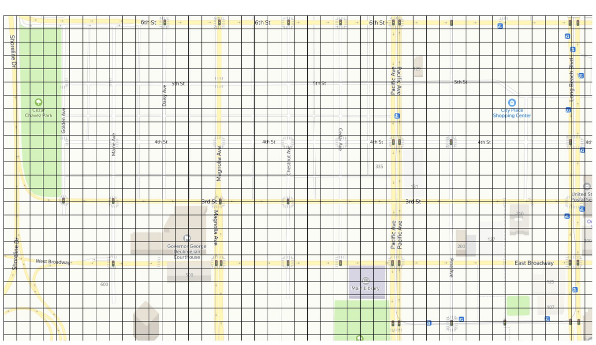


Figure 22: Grid Downtown Map

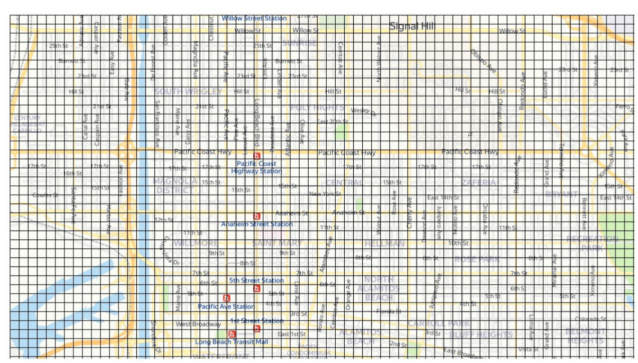


Figure 23: Grid Long Beach Map

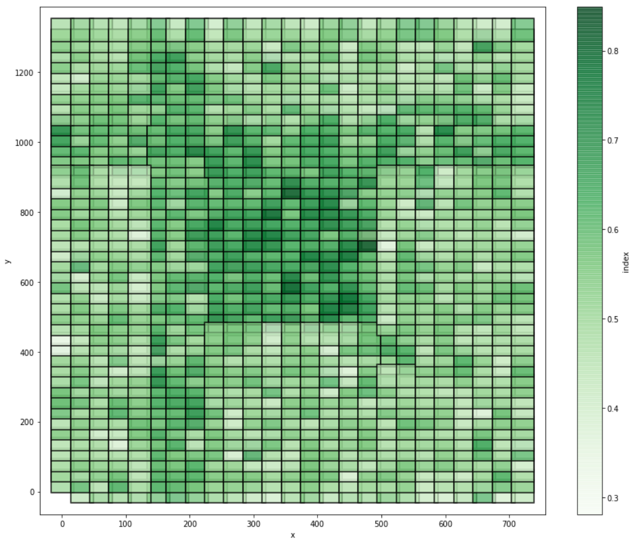


Figure 24: Rendered Image 1

Following grid analysis, we computed trust levels for each grid, utilizing the results to create a score rendering layer. This visual layer, expressed through varying colors and shades, offers an intuitive representation of trust distribution across grids. It aids decision-makers in pinpointing high trust zones and areas requiring enhancement, thereby supporting resource allocation and strategic planning.

The color intensity in each cell corresponds to the value of the index, with darker shades representing higher trust levels and lighter shades indicating lower trust levels.

In addressing real estate evaluation, we introduce a disaster resistance coefficient (DR) to assess a house's capacity to withstand disasters, alongside refining four key indicators—population growth rate, economic growth rate, economic base, and natural risks—for communities like Palm Beach, Florida. Additionally, a house confidence parameter, accounting for the value retention of properties over 25 years or older, ensures that compensation (m) for such properties is adjusted upwards, reflecting their maintained value over time.

The formula for calculating the profit margin p is as follows.

$$p = \frac{BP_0 \cdot (\sigma + TL) \cdot \frac{1}{(1+i)^t} - I \cdot DR \cdot m}{BP_0 \cdot \frac{1}{(1+i)^t}} \tag{12}$$

The values or formulas for BP_0, TL, DR, and σ are outlined as follows.

$$\begin{cases} BP_0 = 20000\$ \\ \sigma = F(l, r, N, n, DR) = \sum_{i=0}^{n} \beta_i \cdot x \\ DR = f(t) \\ TL = TL(N, r, DC) \end{cases}$$

In section 6.1, the equation is given by

$$TL = 0.58N + 0.11r + 0.31DC \tag{13}$$

In this context, TL is defined as the median value of Long Beach, specifically 0.65.

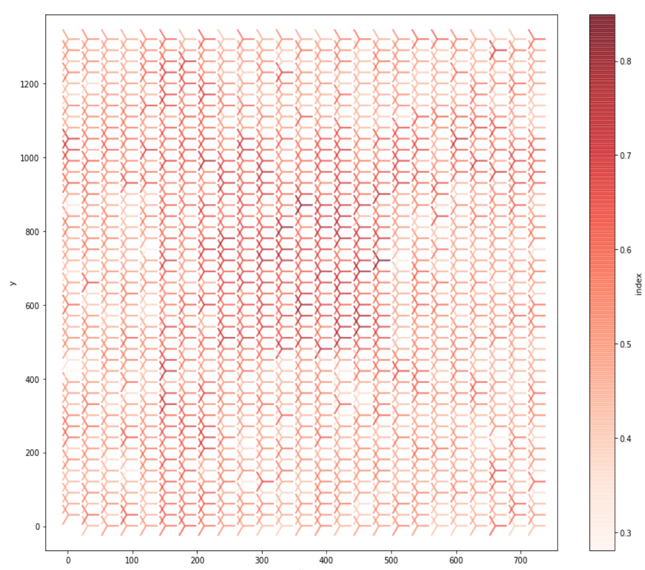


Figure 25: Rendered Image 2

We still use the entropy method to calculate the adjustment coefficient σ, and as a result, we obtained the weight vector, its value is [0.2033436, 0.16624392, 0.32268842, 0.1934229, 0.11430116].

Next, we compiled the data of the disaster resistance coefficient of houses for each year, performed linear regression analysis on these data, and derived the functional relationship between the disaster resistance coefficient of houses and time. The following is a representation of the corresponding fitted image.

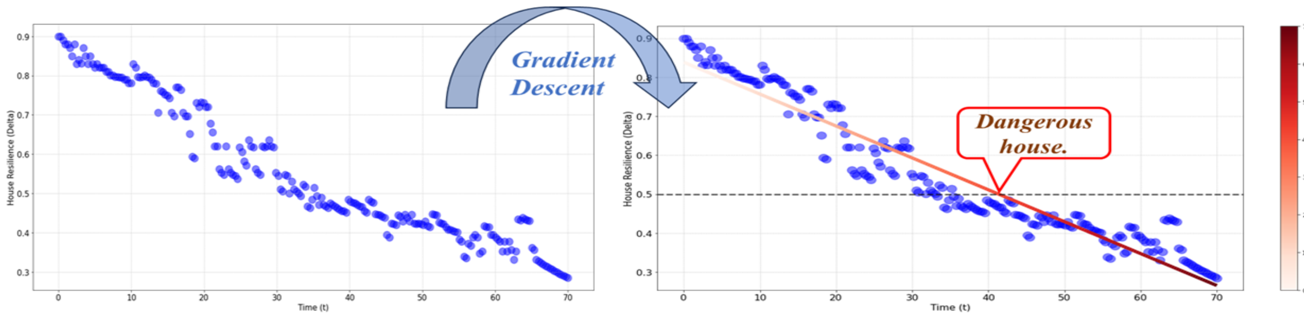


Figure 26: Building's Disaster Resistance Coefficient over Time

We derived the regression equation for the relationship between the house's disaster resistance coefficient and time, that is,

$$DR = f(t) = -0.008186t + 0.838647. \tag{14}$$

Having already determined the equation for p, we can solve for m using this equation, yielding the following result:

$$m = \frac{(\sigma + TL - p)BP_0}{I \cdot f(t) \cdot (1+i)^t} \tag{15}$$

In the same way as we handled the initial question, we continue to classify each city based on adjustment factors, summarizing into four categories. They are 1-1.5, 1.5-1.8, 1.8-2.2 and 2.2-3.0. The corresponding premium intervals have been set as low, medium, high and very high. The following graphic shows the four selectable points on the premium area under a fixed interest rate of 10%, these points correspond to the four types of insurance plans under a 10% interest rate.

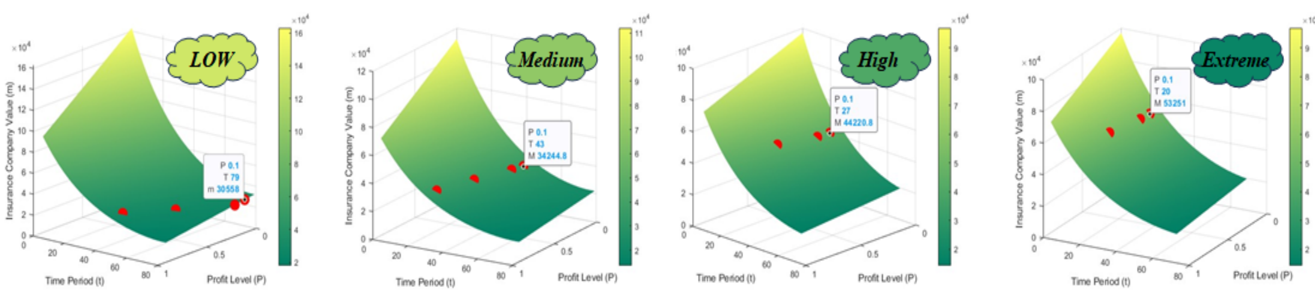


Figure 27: Four Types of Insurance Plans

The following table presents insurance plans matched with various interest rates in four categories. The new model can also achieve profitability in areas with higher risks (taking areas with a risk level of 0.8 as an example).

Table 6: Insurance Premium Plan Conclusions

Range	1–1.5	1.5–1.8	1.8–2.2	2.2–3.0
Index	(0%, 30%)	(30%, 60%)	60%, 80%	Above 80%
Premium Range	Low	Medium	High	Very High
sigma	1.4	1.7	2.0	2.6
P=10%	T=79	T=43	T=27	T=20
P=20%	T=79	T=41	T=26	T=19
P=50%	T=60	T=34	T=21	T=15
P=80%	T=48	T=27	Rejection	Rejection

7 Problem 3

7.1 Data Processing

$$r_{m,n} = \frac{x_{m,n} - r_{min}}{r_{max} - r_{min}} \tag{16}$$

where $x_{m,n}$ denotes the original value of the n^{th} item in the m^{th} region, r_{min} is the minimum value of item n across all regions, and r_{max} is the maximum value of item n across all regions.

For indicators where lower values are preferable, an inverse transformation is applied:

$$r_{m,n} = \frac{r_{max} - x_{m,n}}{r_{max} - r_{min}} \tag{17}$$

The assignment of weights to indicators is critical, as it substantially impacts the precision of the evaluation outcomes. The entropy weight method, known for its objectivity, is utilized to ascertain these indicators' weights in part 7.5.

7.2 CEHM-Protection Model Based on Analytic Hierarchy Process (AHP)

In the context of progressively increasing extreme weather events, a community affected by these events faces the dilemma of relocation and preservation. Community leaders need to assess the cultural, historical, economic, and communal significance of their community to make informed decisions about whether to move or stay. Accordingly, we construct a **CEHM-Protection model** based on the Analytic Hierarchy Process (**AHP**).

The AHP based model consists of three layers: **Goal Layer:** Maximization of cultural heritage value; **Decision Layer:** Relocate or Preserve; **Criteria Layer:** Cultural Index (CI), Economic Index (EI), Historical Index (HI), Maintenance Index (MI).

- **Cultural Value (CI)**

  Given the Cultural Index (CI) equation:

  $$CI = BP_n \cdot TL \cdot \ln(T), \tag{18}$$

  where T is the existence time, BP_n is the natural culture unit value, and TL is the trust level index of the home-buyer community from problem 2. Particularly, if relocation occurs, then the existence time T will become 0, and TL will change, necessitating a recalculation.

- **Economic Index (EI)**

  Economic Value (EI) is given by:

$$EI = \sigma \cdot e^{CI} \cdot \gamma_0 = \sigma \cdot e^{BP_n \cdot TL \cdot \ln(T)} \cdot \gamma_0, \tag{19}$$

  where γ is the natural economic unit value. This leads to the economic judgment matrix. This index reflects the overall economic value of a community, which is essential within the weights of model.

- **Historical Index (HI)**

  Historical Value (HI) is defined as:

$$HI = \int_0^T \ln(\epsilon t + \tau_0)\, dt, \tag{20}$$

  where ϵ represents the natural history level, and τ_0 is the historical adjustment factor.

  For the two plan layers, since the relocation site has no relation to the landmark, a direct and more extreme judgment matrix can be set.

- **Maintenance Index (MI)**

  Maintenance Cost (MI) is calculated by:

$$MI = (1 + DR_0 \cdot I_0)BP_n \cdot \text{year}(t) + \omega_0 \cdot \text{distance}(d_{ij}) + \mu_0, \tag{21}$$

  where I_0 is the community's risk coefficient, DR_0 is the disaster resistance coefficient in problem 2, ω_0 represents the unit relocation cost, distance(d_{ij}) is the moving distance from position i to j, and μ_0 is the inherent relocation cost of the site (depending on the attributes of the building being demolished).

7.3 Structure of AHP

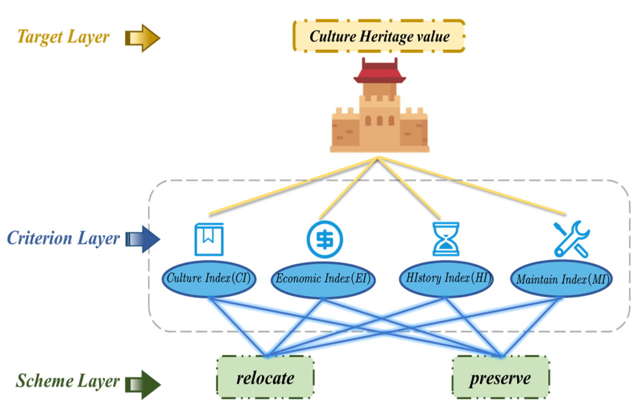


Figure 28: AHP Structure Diagram

We want introduce analytic hierarchy process to establish an evaluation model of four indicators. The hierarchy analysis structure is on the left.

In the hierarchical model's second tier, we construct a pairwise comparison matrix for each preceding layer's element using a 1-9 scale. This process extends to the finest level, represented by the matrix:

$$A = (a_{ij})_{n \times m}, \tag{22}$$

where $a_{ij} > 0$.

By conducting a keyword search on Google Scholar, we found that ”Cultural value” yields 100.2 million results, ”Economic value” returns 89.1 million, ”Historical value” gathers 45.6 million, and ”Maintenance value” collects 11.9 million. Utilizing these findings, we assess the relative significance

Table 7: Comparison Scale for Dimension Intent

Dimension (a_{ij})	Intent (C_i to C_j)
1	Equal
3	Slightly Stronger
5	Strong
7	Obviously Stronger
9	Absolutely Stronger
2, 4, 6, 8	Between the above two adjacent grades

of each criterion and construct a pairwise comparison matrix A for the objective layer. The matrix is given by:

$$A = \begin{bmatrix} 1 & 2/3 & 4 & 3 \\ 2 & 1 & 6 & 5/2 \\ 1/5 & 1/5 & 1 & 1/2 \\ 1/3 & 1/6 & 3 & 1 \end{bmatrix}$$

7.4 Consistency Check

The judgment matrix of the criterion layer obtained by expert scoring is a fourth-order matrix and four second-order matrices. The consistency test of the fourth-order matrix A is carried out below.

The **maximum eigenvalue** λ of matrix A, as computed by MAtlAB, is 4.0642, and the normalized eigenvector is $\omega = [0.3275, 0.4661, 0.0735, 0.1329]$. Consequently, this eigenvector serves as the weight vector for cultural, economic, historical, and maintenance indices. To ensure the reliability of our comparison matrices, we evaluate the consistency index (**CI**) and the random consistency index (**RI**):

$$CI = \frac{\lambda - n}{n - 1} \tag{23}$$

where n represents the order of matrix A, and RI values are obtained from a standard table. Upon calculation, $CI = 0.0214$. Subsequently, the consistency ratio (**CR**) is calculated as:

$$CR = \frac{CI}{RI} \tag{24}$$

The resulting $CR = 0.0240 < 0.1$, indicating that the degree of inconsistency falls within an acceptable range, thus passing the consistency test. The remaining four matrices are all **second-order matrices** with CR values of 0, and all pass the consistency test

7.5 CEHM-Protection Model Assessment

The final score of the CEHM-Protection Model is 0.4904 for Preserving and 0.5096 for Relocation, indicating that moving out is a more appropriate choice.

Given minor differences in indices for relocation and preservation, on-site preservation emerges as a viable option. We propose a conservation strategy grounded in the weights of four criteria. Primary actions focus on enhancing values difficult to alter in the short term, such as Historical Index (HI):

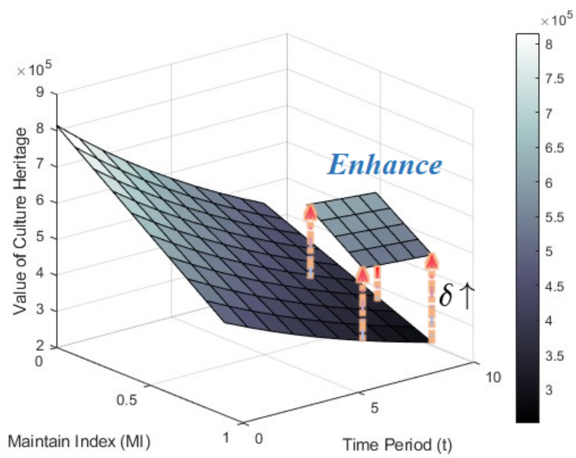
Table 8: Assessment of CEHM-Protection Model

CEHM-Protection Model			
Factor	Index	Decision	Weight
CI	$\omega_{CI} = 0.3275$	Preserve	$\omega_{CIP} = 0.8333$
		Relocate	$\omega_{CIR} = 0.1667$
EI	$\omega_{EI} = 0.4661$	Preserve	$\omega_{EIP} = 0.2857$
		Relocate	$\omega_{EIR} = 0.7143$
HI	$\omega_{HI} = 0.0735$	Preserve	$\omega_{HIP} = 0.8889$
		Relocate	$\omega_{HIR} = 0.1111$
MI	$\omega_{MI} = 0.1329$	Preserve	$\omega_{MIP} = 0.1429$
		Relocate	$\omega_{MIR} = 0.8571$

- **Simultaneously enhancing the economic value (EI) and cultural value (CI):** Mainly by altering the adjustment factor σ through increasing local economic growth rates and foundations (e.g., promoting tourism to attract investment, and developing cultural and creative industries). This can also boost cultural confidence, collectively creating a positive feedback loop that continuously fosters the growth of economic value.

- **Lowering maintenance cost (MI):** Mainly by conducting regular upkeep of the artifacts (increase the value of DR) to improve their resilience against extreme weather, thus reducing maintenance costs and effectively preserving the community's cultural heritage.

  The contribution of these measures to enhancing the value of cultural heritage is presented in the following figures.



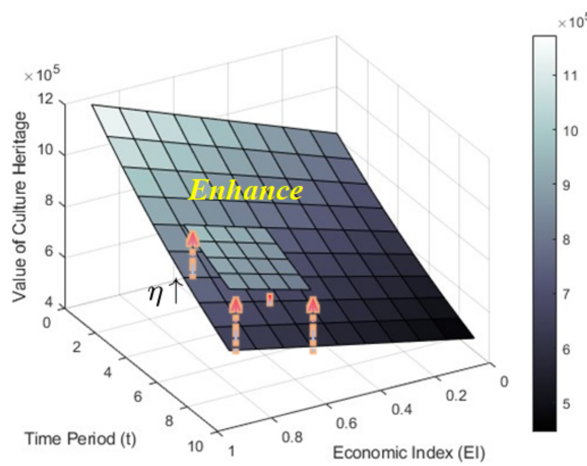


Figure 29: On-site Preservation Enhancing Strategies

As is shown in the figure, both (DR) and (TL) increase cultural heritage value.

8 Problem 4

8.1 Selection and Value of Historical Landmarks

The historical landmark we've selected is known as Castle Clinton, a circular sandstone structure located in Battery Park at the southern tip of Manhattan in New York City. The building was constructed between 1808 and 1811. Today, Castle Clinton is a landmark of New York City, an American national monument, and has been listed in the National Register of Historic Places.

The history of Castle Clinton illustrates the significant role it played in the development of America. As a national monument, it embodies cultural and historical values. Given its location, this landmark might face a series of threats due to climate change, such as sea level rise and an increase in extreme weather events, factors that could pose challenges to its preservation and maintenance.

Figure 30: Weight Distribution of σ

8.2 Cost-Benefit Analysis Model

The Cost-Benefit Analysis Model is divided into two parts,
namely the cost of Clinton Fortress and the income of Clinton Fortress [4].

We need to gather historical climate and economic data from the region where Clinton Castle is located, so that these data can be incorporated into subsequent models. The following is a schematic diagram of rainfall and temperature data from the area where Clinton Castle is located.

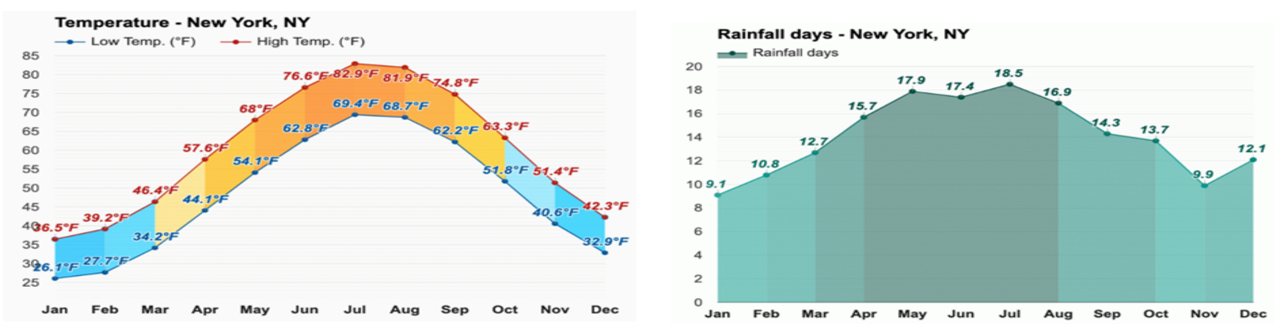


Figure 31: New York Rainfall and Temperature

Cost of Clinton Fortress

Firstly, we will determine the value of I using the risk assessment model.Through calculation, we obtain $I = 0.4572$, and this area belongs to the medium premium zone. Then, through the function $\sigma = F(l, r, N, n)$, we will further clarify which premium zone it specifically belongs to. According to the formula:

$$p = \frac{BP_0 \cdot (\sigma + TL) \cdot \frac{1}{(1+i)^t} - I \cdot m}{BP_0 \cdot \frac{1}{(1+i)^t}} \tag{25}$$

The calculation resulted in, under a balanced budget condition where $p = 0$, the unit base premium BP_0 corresponding to m fluctuates over time.Substitute the result into formula (21), which serves as its natural economic value in units, and finally obtain:

$$\text{Costs} = \frac{(1 + DR \cdot I)\sigma BP_0}{I(1 + i)^t} \tag{26}$$

Income of Clinton Castle

To calculate the income of Castle Clinton, it is necessary to use the CI, EI, and HI in the protection model, referring to formula(18,19,20).

Multiply CI, EI, HI and their respective weights $\omega_{CI}, \omega_{EI}, \omega_{HI}$ by their corresponding calculation formulas to get:

$$Benefits = \beta_1 CI + \beta_2 EI + \beta_3 HI \tag{27}$$

After calculation, we obtain $\beta_1 = 0.3777, \beta_2 = 0.5375, \beta_3 = 0.0848$ Then we obtain the value expression of Clinton Castle

$$\text{Value} = (B - C)\bar{p}_0 \tag{28}$$

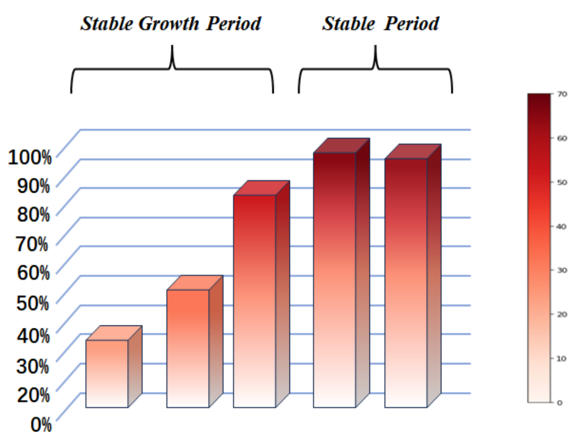


Figure 32: Change in Value over Time

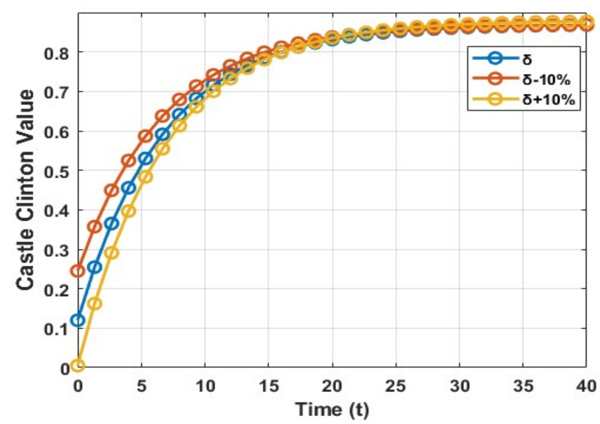


Figure 33: Castle Clinton Value

9 Sensitivity Analysis

The premium adjustment factor σ in the CBA model's profitability is subjectively chosen. Literature suggests that incorrect parameter selection can impact result accuracy. In our analysis of Castle Clinton's value as a historical landmark, σ emerges as the crucial parameter influencing the landmark's evaluated worth.

To assess our model's sensitivity, we perform an analysis on the σ parameter, varying it by $\pm 10\%$. Holding other indicators at their optimal values, we examine how the net profit ($Value = Benefits - Costs$) evolves over time. The outcomes, depicted in the adjacent chart, illustrate the impact of σ adjustments on the model's value dynamics.

The stability of our model is demonstrated by Castle Clinton's value, which remains relatively unaffected by variations in the adjustment factor σ. This indicates not only the model's robustness but also its ability to mitigate fluctuations through the balancing effects of other indicators. Consequently, the landmark's value is primarily influenced by its cultural and historical significance, aligning with expectations and fulfilling the criteria for an effective model.

10 Model Evaluation

Strength:

1) The model integrates **the compound interest present value formula** from economics, considering **currency depreciation** in the calculation of policy value. It ensures **sustainability** and **resilience** in the insurance company's profitability by maintaining that the derivative of profit level p with respect to time t is always non-negative.

2) By innovatively combining **methods of attracting customers** when considering policy rejection, the model keeps the insurance payout m above a certain **adjustment factor** from the customer's perspective. This not only secures the insurance company's benefits but also considers customer attraction, ensuring the **flexibility** of the company's profits.

3) **The landmark value assessment model** quantifies costs by aptly integrating the local value of the landmark's community through the adjustment factor in **the premium model**, profoundly displaying the cost of maintaining historical landmarks with the economic value in natural units.

Weakness:

1) Assuming that the probability of extreme weather risk is equivalent to the policy payout probability might be somewhat absolute.

2) The construction of historical factors in the model for historical landmarks carries a degree of subjectivity.

11 Reference

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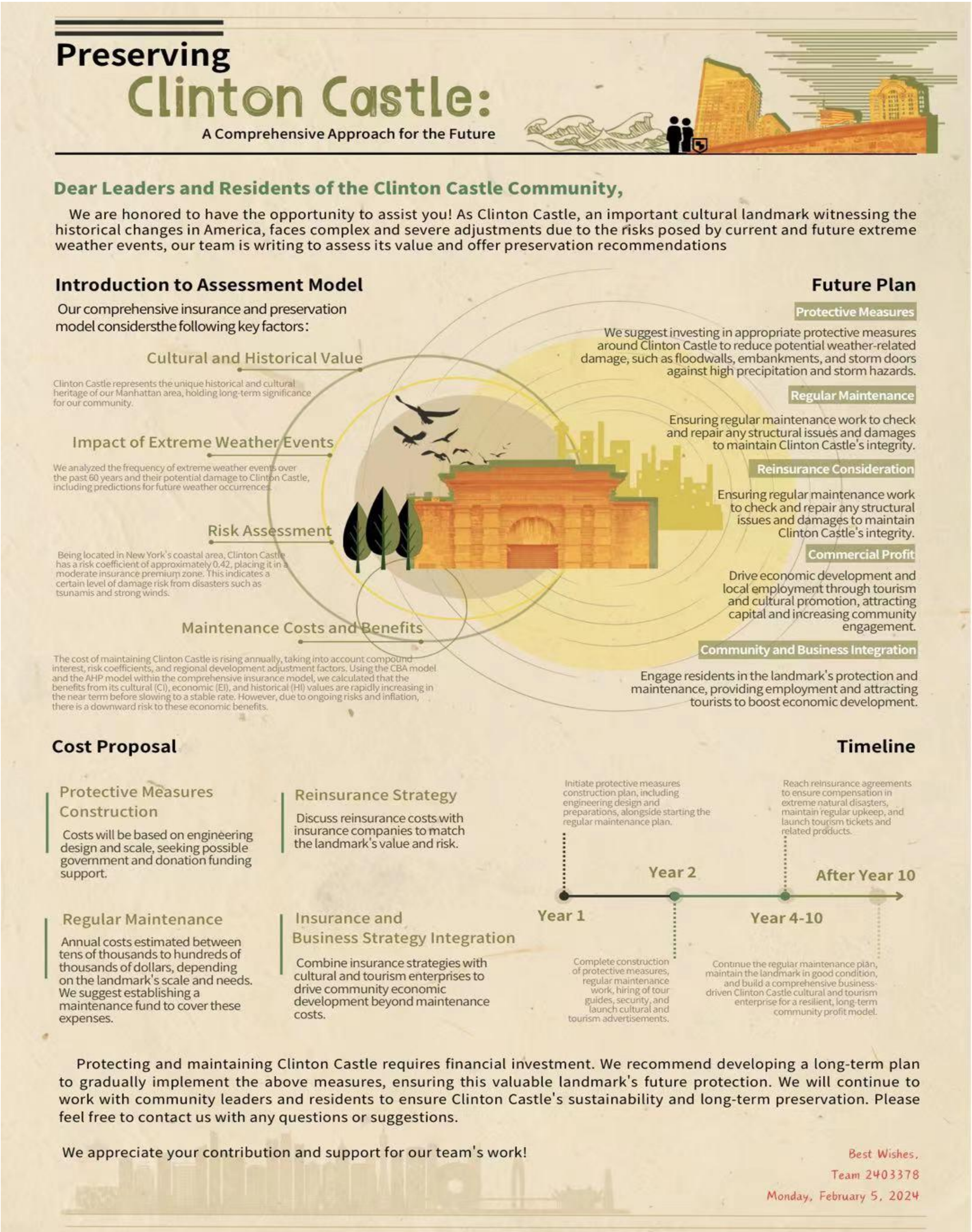
[7]Al-Harbi, K.M.A.-S. (2001). Application of the AHP in project management. International Journal of Project Management, 19(1), pp.19-27.

12 Appendix


Preserving
Clinton Castle:
A Comprehensive Approach for the Future
Dear Leaders and Residents of the Clinton Castle Community,
We are honored to have the opportunity to assist you! As Clinton Castle, an important cultural landmark witnessing the historical changes in America, faces complex and severe adjustments due to the risks posed by current and future extreme weather events, our team is writing to assess its value and offer preservation recommendations
Introduction to Assessment Model
Our comprehensive insurance and preservation model considersthe following key factors:
Cultural and Historical Value
Clinton Castle represents the unique historical and cultural heritage of our Manhattan area, holding long-term significance for our community.
Impact of Extreme Weather Events
We analyzed the frequency of extreme weather events over the past 60 years and their potential damage to Clinton Castle, including predictions for future weather occurrences.
Risk Assessment
Being located in New York's coastal area, Clinton Castle has a risk coefficient of approximately 0.42, placing it in a moderate insurance premium zone. This indicates a certain level of damage risk from disasters such as tsunamis and strong winds.
Maintenance Costs and Benefits
The cost of maintaining Clinton Castle is rising annually, taking into account compound interest, risk coefficients, and regional development adjustment factors. Using the CBA model and the AHP model within the comprehensive insurance model, we calculated that the benefits from its cultural (CI), economic (EI), and historical (HI) values are rapidly increasing in the near term before slowing to a stable rate. However, due to ongoing risks and inflation, there is a downward risk to these economic benefits.
Future Plan
Protective Measures
We suggest investing in appropriate protective measures around Clinton Castle to reduce potential weather-related damage, such as floodwalls, embankments, and storm doors against high precipitation and storm hazards.
Regular Maintenance
Ensuring regular maintenance work to check and repair any structural issues and damages to maintain Clinton Castle's integrity.
Reinsurance Consideration
Ensuring regular maintenance work to check and repair any structural issues and damages to maintain Clinton Castle's integrity.
Commercial Profit
Drive economic development and local employment through tourism and cultural promotion, attracting capital and increasing community engagement.
Community and Business Integration
Engage residents in the landmark's protection and maintenance, providing employment and attracting tourists to boost economic development.
Cost Proposal
Protective Measures Construction
Costs will be based on engineering design and scale, seeking possible government and donation funding support.
Reinsurance Strategy
Discuss reinsurance costs with insurance companies to match the landmark's value and risk.
Regular Maintenance
Annual costs estimated between tens of thousands to hundreds of thousands of dollars, depending on the landmark's scale and needs. We suggest establishing a maintenance fund to cover these expenses.
Insurance and Business Strategy Integration
Combine insurance strategies with cultural and tourism enterprises to drive community economic development beyond maintenance costs.
Timeline
Initiate protective measures construction plan, including engineering design and preparations, alongside starting the regular maintenance plan.
Year 1
Year 2
Complete construction of protective measures, regular maintenance work, hiring of tour guides, security, and launch cultural and tourism advertisements.
Reach reinsurance agreements to ensure compensation in extreme natural disasters, maintain regular upkeep, and launch tourism tickets and related products.
Year 4-10
After Year 10
Continue the regular maintenance plan, maintain the landmark in good condition, and build a comprehensive business-driven Clinton Castle cultural and tourism enterprise for a resilient, long-term community profit model.
Protecting and maintaining Clinton Castle requires financial investment. We recommend developing a long-term plan to gradually implement the above measures, ensuring this valuable landmark's future protection. We will continue to work with community leaders and residents to ensure Clinton Castle's sustainability and long-term preservation. Please feel free to contact us with any questions or suggestions.
We appreciate your contribution and support for our team's work!
Best Wishes,
Team 2403378
Monday, February 5, 2024