Problem Chosen	2024 MCM/ICM Summary Sheet	Team Control Number
E		2429973

Insurance Beyond Survival: Resilience and Construction from Natural Disaster

The growing occurrence of severe weather phenomena is leading insurers to limit the scope of their coverage offerings. In the headlines are the states of Florida and California in the United States, yet the influence of extreme weather extends beyond just coastal areas. This includes a wide range of weather-related incidents, such as intense storms, hurricanes, floods, and wildfires, impacting regions globally. "Natural disasters caused global economic losses of about $**313 billion** in 2022", but "less than half ($**132 billion**) of this amount was insured", which "creates an insurance protection gap of **58**%".[1] The gap is a serious impediment to the sustainability of property insurance, so efforts to find solutions to reduce this gap are vital

Our goal in this scientific research is to develop two main models to address the issue: **Insurance Model** and **Preservation Model**. Insurance model aims to guide both insurance companies and their clients, real estate business, to make decisions that are in the best economic interest. Meanwhile, Preservation Model considers more than just economic interests. The human spirituality is an important consideration in governmental decision-making, so the cultural and community values of the building are also considered importantly in this model in order to facilitate optimal decision-making.

For **task 1**, we created the **Insurance Model** to help insurance companies to decide when and to what extent to underwrite policies. This step is the vital data setting process of the whole modeling regarding insurance, and our quantitative research is based on **Google Cloud Public Datasets**. We considered several natural disasters (especially strong storms) as factors and included analysis of **Game Theory** to count the client's response to policy underwrite. We used **multiple linear regression, k-mean clustering, and machine learning** to classify and fit the data. We referred to 2 places which encountered natural disasters to testify our model.

For **task 2**, following by our first **Insurance Model**, we adapted it to help real-estate clients to evaluate construction of new sites. Here we analyze the impact of **economic, policy, social**, and other variable factors, focusing primarily on profitability, risk, and insurance amounts, to provide property developer and real estate owners with comprehensive recommendations for coping with extreme weather and insurance changes.

For **task 3**, we took cultural and economic factors in to account to analyze the value of preservation of historical sites, creating our **Preservation Model**. While the **risks** of extreme weather and high maintenance **costs** are important considerations when talking about cultural and community architecture, it is also important to think about the dimensions of c**ivilization and cultural identity**, and our model is designed to balance these influencing variables.

For **task 4**, we used **China's Great Wall** as a case study, utilizing our **Insurance Model** and **Preservation Model** to recommend policy making. We explored the structure of the Great Wall and the extreme weather conditions around it, and made conservation recommendations to the Chinese and Beijing governments on **cultural values and maintenance costs**, presented in a one-page letter.

Additionally, we provide a **Sensitivity Analysis** exploring how our models respond to the change in major factors. We verified that our model is composite of reality and applicable to different scenarios.

Keywords: Insurance Model, Preservation Model, Game Theory, Extreme Weather, Economic Interests, Culture and Community Values, Decision and Policy

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1 Introduction

1.1 Background

The sustainability of property insurance is increasingly challenged by the rising frequency and intensity of extreme weather events, exacerbated by climate change. This has led to a surge in claims and a significant increase in insurance premiums, making property insurance more expensive and difficult to obtain. The variation in weather-related risks around the world and a growing insurance protection gap further complicate the situation, posing a dilemma for both insurers and property owners regarding profitability and affordability.

Figure 1: Rising Homeowners' Insurance Premiums Are Squeezing Retirees - The New York Times

The widening protection gap not only heightens the risk and hardship faced by individuals, but it also serves as a crucial measure of a society's economic and social robustness. Given the magnitude of losses resulting from climate-related catastrophes, the insurance sector alone cannot bear the entire weight. Nevertheless, the industry possesses extensive knowledge in developing creative solutions for both reducing and redistributing risk. To make the property insurance sustainable, the improvement methods mainly include **"Advanced Risk Modelling"**, **"Spreading the Load"**, **"New Government-Supported Programs"**, and **"Long-term Risk Reduction"**.[2] We were inspired by those ideas and developed our own solutions.

As climate change progresses, the influence of severe storms globally will keep changing, further complicating the task of setting appropriate insurance rates for regions most affected by natural catastrophes. Through studying the spatial patterns and historical impact of these storms, insurance companies can gain a clearer picture of the associated risks, allowing them to incorporate this understanding into their dynamic premium pricing strategies. Dynamic Premium Pricing is a multifaceted challenge, where assessing risk from storms plays a crucial and impactful role.

1.2 Restatement of the problem

We restate the tasks to make ourselves more aware of the focus of our work.

- In **task 1**, we created a model assisting insurers in determining the optimal times for policy underwriting in regions facing a growing risk of severe weather, thereby guaranteeing the sector's endurance and robustness.
- In **task 2**, we adapted an insurance model to guide future real-estate decisions on where, how, and whether to construct properties in a way that serves growing communities effectively.
- In **task 3**, we developed a preservation model for community leaders to identify and protect buildings of cultural, historical, economic, or community significance in their community.
- In **task 4**, we evaluated a historic landmark in a high-risk weather region using insurance and preservation models. and composed a one-page letter to the community with a preservation plan, timeline, and cost proposal based on the model insights.

1.3 Our Work

Based on our tasks, we have done the following works:

- We analyze Severe Storm Event data produced by NOAA available through the **Google Cloud Public Datasets** to better understand the risk that severe storms present to insurance. We use BigQuery Geographic Information Systems (GIS) to combine the storm data with US zip code boundary data also available through the Cloud Public Datasets Program.
- For the **Insurance Model**, we divided it into two parts regarding two parties: Risk Assessment and Economic Model. The first one, designed mainly for insurance companies, include physical housing evaluation and environmental (climatic) assessment. The second half, for both insurance and real estate companies, involves game theory to help balance various considerations.
- For the **Preservation Model**, as this is mainly facing the government to help them come up with a reasonable policy for the preservation of historic buildings, the model will contain both Cultural and Metrics Evaluation. We included UNESCO and OEC data to help model the result.
- We then conducted **Case Study** regarding China Great Wall to give advice on the specific historical and cultural architecture.
- We also display our **Sensitivity Analysis** to show the efficiency and universality of our model.

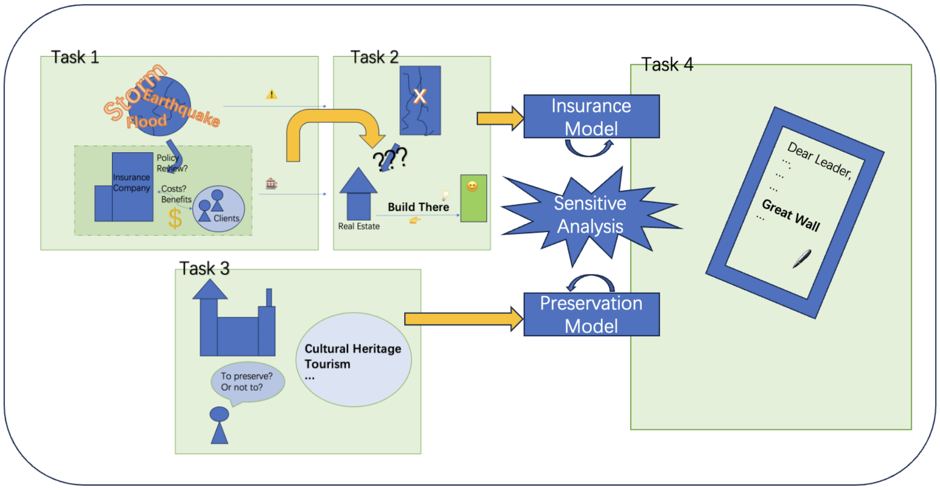

Figure 2: The Framework of Our Study

2 Model Preparations

- **Statistics gathered from websites are accurate and dependable.** Our data source are generally from Google Cloud Public Datasets and other public database like UNESCO and OEC.
- **The total formula considers a sufficient number of variables.** We not only considered the major factor, extreme weather, but also took variables like quality of architecture and regional population into consideration.
- **We selected the most representative portion of influencing factors.** As the most destructive extreme weather condition for buildings, we chose storm as the main impact factor to be brought into the calculation and added other types of disasters after it.
- **We analyzed data over different time spans as required.** For the analysis of overall changes in extreme weather, we chose a time span of decades, while for the fine analysis of categorization, etc. we chose a time span in months.
- **We distinguish between direct and indirect influences.** We removed extreme weather conditions that did not directly damage the building from our analysis.

2.1 Notations

Since the variable names are all short, we don't use symbols to refer to them. All the names of extreme weather events and other influencing factors will be written in complete English. Specific formulas may use letters to indicate some parameters, which will be explained below.

2.2 Data Collection and Cleaning

We searched the literature for relevant datasets and classification criteria as follows:

1. **Severe Storm Event data produced by NOAA**
2. **BigQuery Geographic Information Systems (GIS)**
3. **US zip code boundary data**
4. **OEC**
5. **EM-DAT**
6. **PD&R**
7. **Cultural Intelligence Center**

The data preparation section focuses on **setting up the environment** (including calling packages), reading representative data, and getting authentication. We mainly use **Python 3** and **BigQuery** to read, analyze, and visualize the data. We take a look at the storms data briefly by reading only one month of data. We are using the BigQuery magic command to read the data into a Pandas DataFrame.

3 The Calculation of Damage Cost

3.1 The Calculation of Damage Cost

As climate change progresses, it increasingly complicates the prediction of effective insurance pricing in regions most affected by natural disasters. This is due to the evolving nature of severe storms worldwide. By examining the geographical patterns and historical impacts of these storms, insurers can gain a deeper understanding of the associated risks, aiding them in adjusting their premium pricing dynamically. Severe Storm Event data from NOAA, accessible via the Google Cloud Public Datasets Program, plays a crucial role in this analysis. The demonstration leverages BigQuery Geographic Information Systems (GIS) to integrate this storm data with US zip code boundary information, also available through the program. This boundary data is part of a broader collection of over 10 datasets in BigQuery, which detail various US boundaries like states, zip codes, counties, and more.

The main formula of damage cost is described as following:

$$\text{DAMAGE COST} = \Sigma_{i=1}^{10} c_i \times EVENT_i$$

The events include extreme weather events as well as the quality of the building itself. Due to the exclusion of non-direct events, we consider each event to be independent of each other and to have a different degree of influence on the overall cost. So we assign different coefficients to each event element and sum them overall. Then, we are going to determine the parameters with more modeling steps.

3.2 Explore the storms and geographical data

To start with, we firstly read the storm data for the past 5 years and look at the distribution of number of storms and damage costs by state and event type. Then we try two kinds of linear regression methods:

First, we use **Multi-variable Linear Regression** by state, where the number of each type of event is an independent variable, and the total damage cost is the dependent variable. We used the number of each disaster to predict the amount of damage with fair accuracy. Housing quality is also an important variable because it is directly related to the amount of loss, but since it cannot be fully quantified, we add it to the fixed costs in the subsequent modeling process. Now we determined the parameters of the events as following (multidimensional data is difficult to observe):

The R-squared Value: 0.7535021633779587
The y-intercept: -7249028671.032703
Coefficients: 7.20234231e+06, -2.40277641e+06, 9.79652268e+05, -4.91867522e+04, 2.40920037e+09, -1.75741893e+08, -2.25140482e+06, 1.72155903e+06, -3.82513974e+07, 2.72052191e+07

Then, we tried **Single-variable Linear Regression**, where the total number of events is the independent variable, and the total damage cost is the dependent variable. The poor accuracy of using the total number of disasters to predict the amount of money lost shows that you cannot just look at the number of disasters, and that the impact of type is significant.

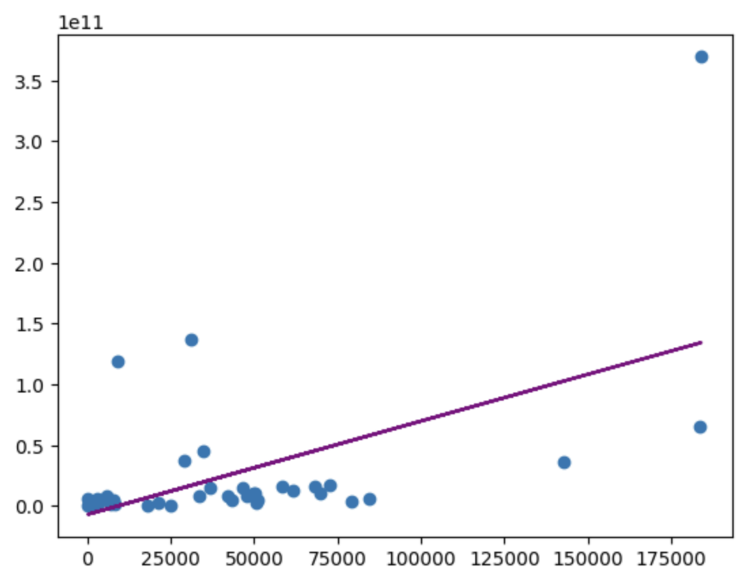

Figure 3: Inaccuracies shown by Single-variable Linear Regression

So having known the appropriate regression model and parameters, we now want to make predictions about future trends. We first tried tweaking the SQL statement above to select the disaster data for each category so that we could categorize and predict trends, but it didn't work as well as we would have liked. We then query here the total number of disasters across the U.S. over the last 70 years, and can see that the data form a more standard exponential growth, and the trend can be fitted by linear regression. By combining this model that predicts the number of future disasters with k-mean clustering, regression, and other models that predict the relationship between disaster conditions and loss amounts, it is possible to predict the amount of future payouts for pricing purposes.

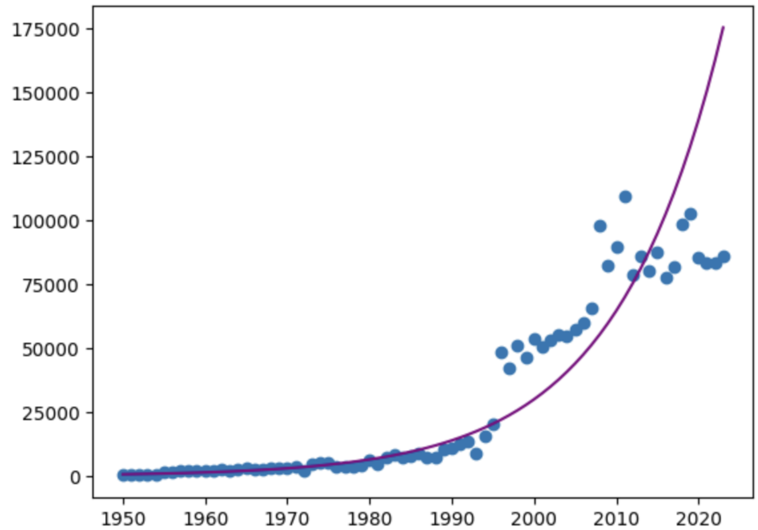

Figure 4: Trends in recent years

Previously we did a regression analysis between number of events and damage cost, but there exists several outliers in our graph. This is because not all events have equal damage, and the severity of the events should also be considered. Below is a graphical illustration. The following icons further illustrate the differences in hazard levels for different types of hazards in different geographic locations to motivate the use of k-mean clustering. by predicting clusters, it is possible to model different regions separately and thus take this issue into account in the model.

Clearly, there are only a handful of storm types that are most destructive, and a few states experience much more severe damage than the others. This is actually very much in line with our general knowledge because each state has a different geographic location, type of natural climate, and topographical features, and certain features will be more likely to cause more destructive natural disasters. For example, coastal states are more likely to be devastated by storms than inland states; mountainous states are more likely to be devastated by landslides caused by extreme rainfall than plains states; and states with a lot of water are more likely to be threatened by flooding than drier states. Data maps for specific climate types and states with extreme weather damage are shown below:

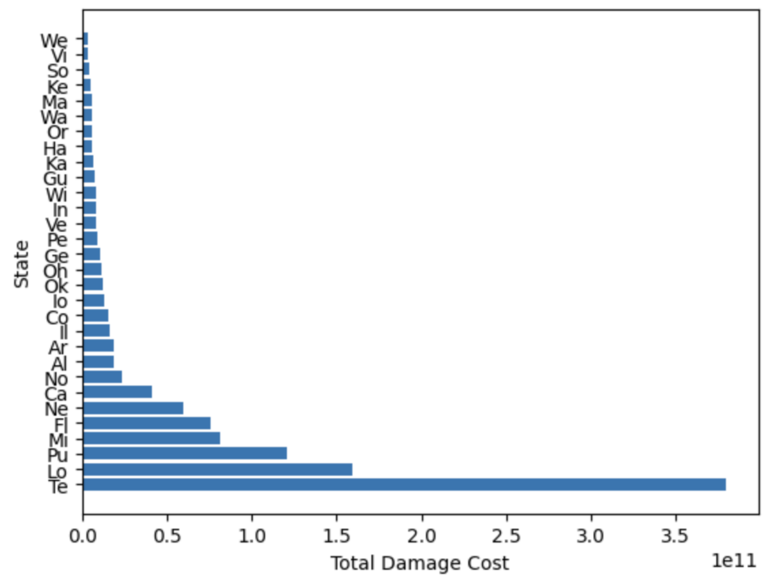

Figure 5: Total Damage Cost by States

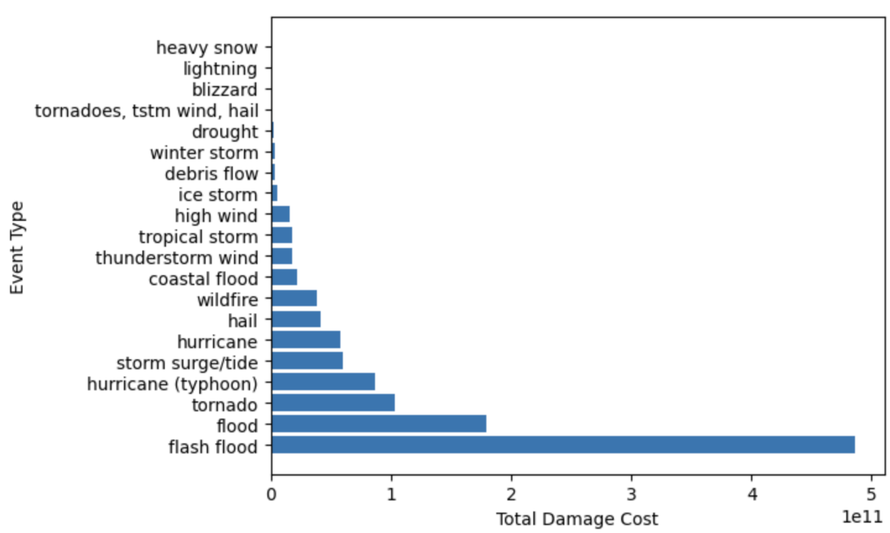

Figure 6: Total Damage Cost by Damage Type

Building on the analysis and graphical representations previously discussed, we can refine our dataset to focus specifically on those states and types of events that are responsible for the greatest amount of damage. This targeted approach allows for a more efficient and meaningful analysis, especially when dealing with large and complex datasets.

To enhance our understanding and make our findings more accessible, we have developed a series of more intuitive charts. These charts are crafted following the guidelines and best practices suggested by Google's program. This not only ensures that our visualizations are of high quality but also that they are easy to interpret.

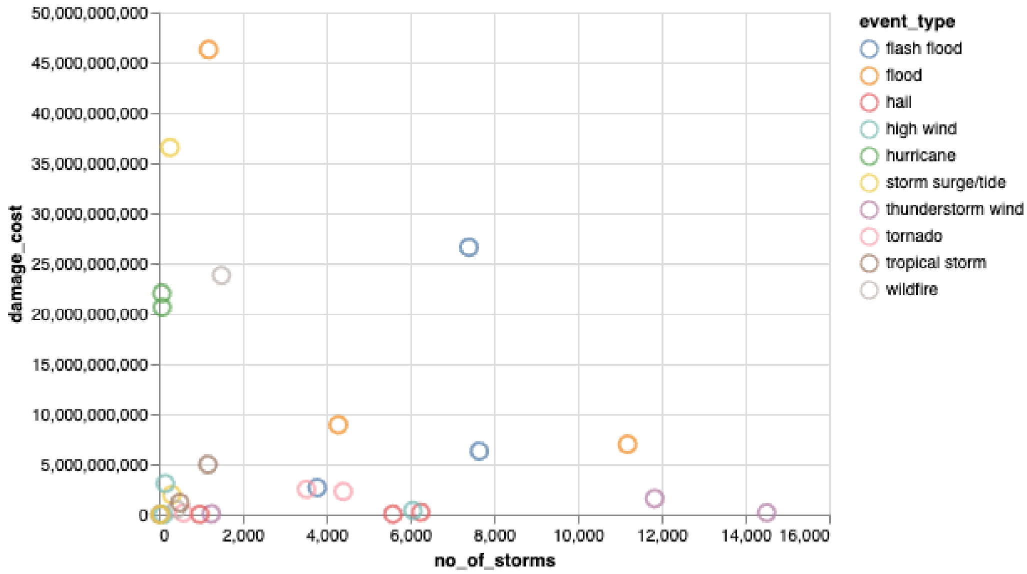

Figure 7: Total Damage Cost by Number of Storms

Now, let's dig deeper into the dataset by analyzing the top states of interest - Texas, California, Lousiana, Georgia and Florida to see how their impact varies by zip code. This would enable to calcuate the risk factor at a more granular level based on the insured's zip code.

We need to query the zip code data from Big Query by determining which zip code each event falls under. We can leverage Big Query's GIS functions to do this in SQL itself. Let's look at how these zip codes are distributed by number of storms and their impact in terms of damages to property and/or crops.

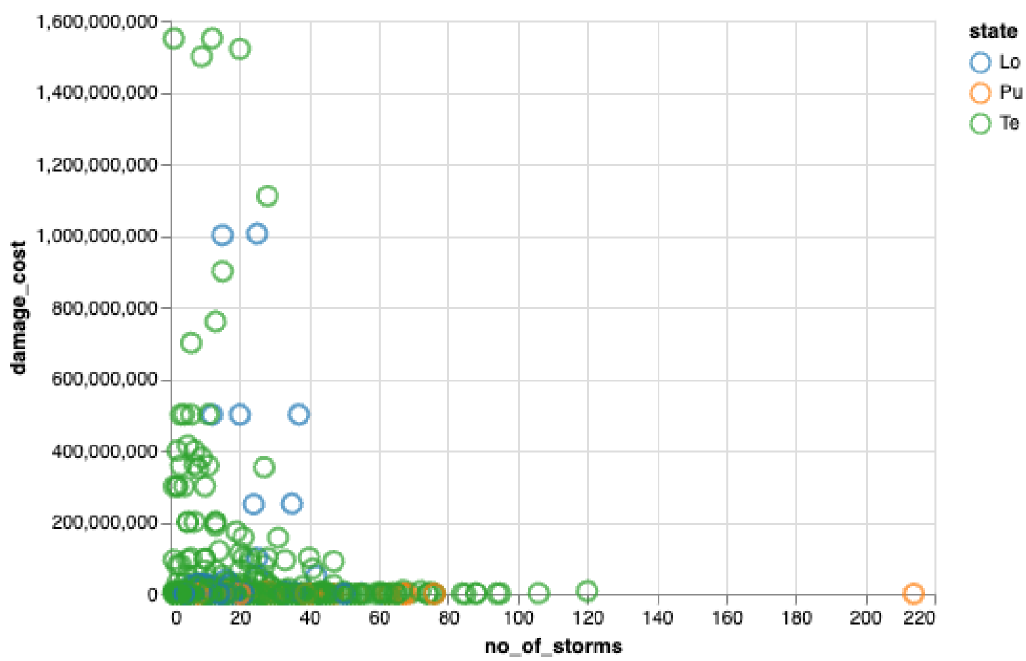

Figure 8: Total Damage Cost by Number of Storms, Categorized by State

The exploration of data and the patterns we identified so far gave us a fair sense of weighing in the risk factor for various locations based on the historical storm data. However, as we have seen, the data changes over time and so are the patterns of risk profiles of various locations, which calls for repeated and complex analysis over the time. Also,deriving the insights at the most granular level at scale proves challenging with ad hoc analysis.

Let's try to build a machine leaning model that can group zip codes into logical risk profile clusters based on the storm data. This way, we can retrain the model as and when we get new data and reap the benefits of automatic categorization with fair accuracy.

3.3 BigQuery ML to cluster the zip codes based on cost of damages to property and crops

We used a BigQuery dataset to create the ML model in. We built the k-means algorithm and selected three of the most disaster-prone and more representative states to analyze. Let's create a K-Mean clustering model with 6 clusters of zipcodes based on number of storms, event type, damage cost. We then evaluate the model to see how it performs and get the performance evaluation of the k-means algorithm: the Davies–Bouldin index (DBI) is 1.202609, while the mean squared distance is 1.488091. The DB index is fairly low for the model to be acceptable. Please feel free to experiment with the number of clusters and input features to fine tune the model as needed.

Now, let's evaluate the model by providing Georgia data as input and then predict the clusters based on the model. After that, we look at the clusters and see if they are meaningful.

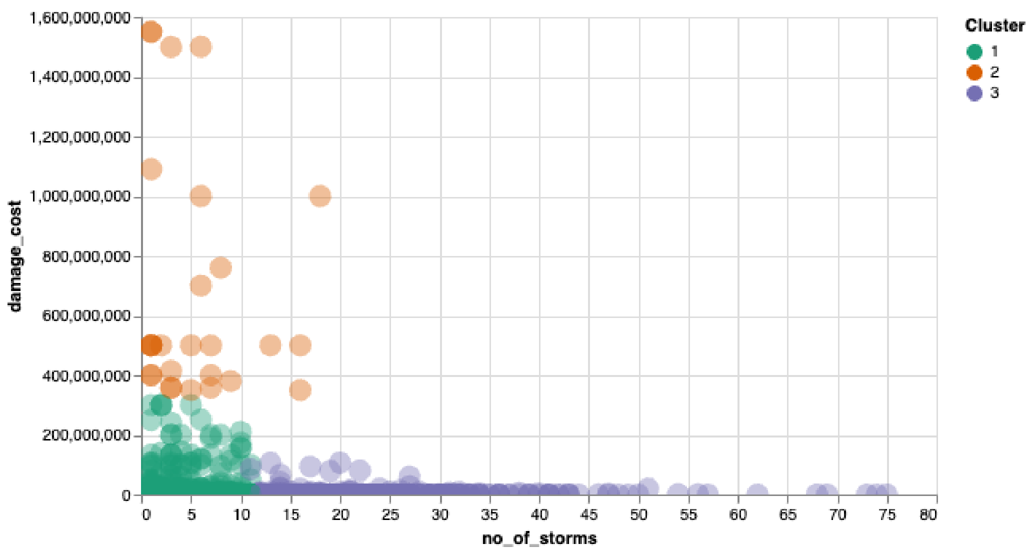

Figure 9: Cluster View Trial

The above figure is a better visualization, you can see that the 3 different clusters represent different data points. For example, cluster 2 represents some areas with occasional high-intensity disasters, and 3 is a low-intensity frequent occurrence of disasters. The clusters of zip codes do indicate some resonable patterns, that can be translated to different risk profiles. Looking at one state - California, for example, help identify variance within a state:

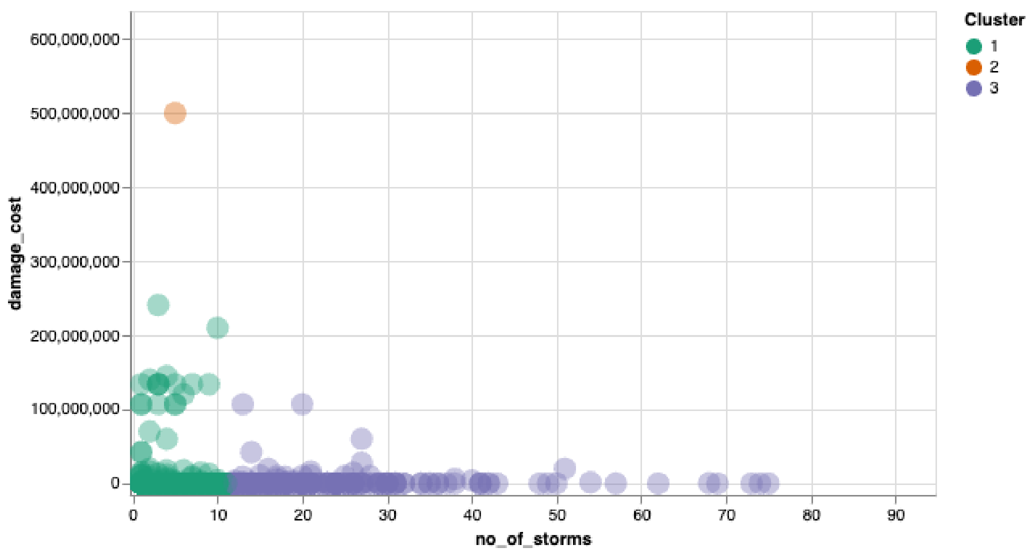

Figure 10: Cluster View for California

We can extend the above to interpret the distribution of clusters or risk profiles for different states:

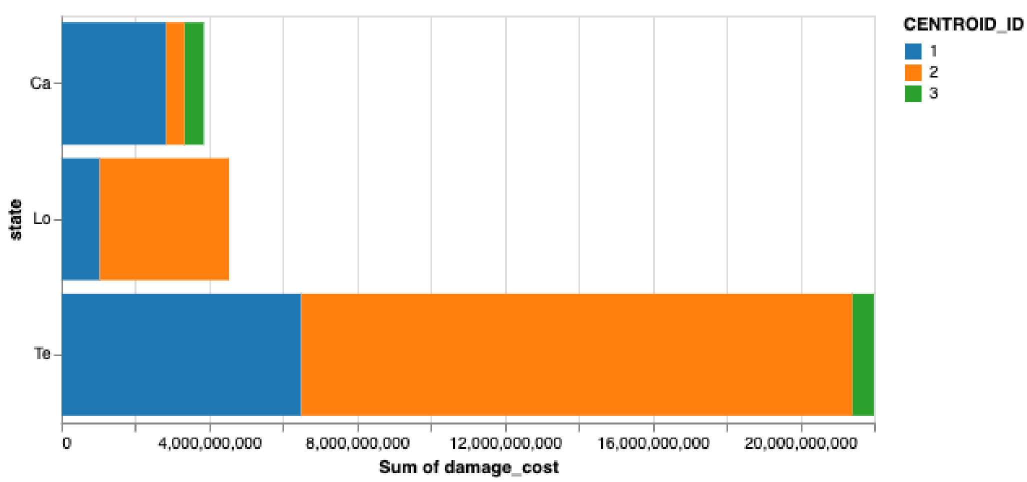

Figure 11: Distribution of Clusters or Risk Profiles for the Three States

This section and the previous section basically complete our computational modeling of damage cost. In the first part of our first model, the Risk Assessment section, we will expand on the above analysis and address the comparison between the states of Tennessee and Louisiana in more detail.

4 Model I: Insurance Model

4.1 Risk Assessment

We would like to build a regression for a single cluster to gain more insight. Here, Cluster 1 (primarily the Louisiana zip code 70xxx-71xxx area) was selected for analysis here in the hope of obtaining a model specific to this area. It can be seen that small areas have local characteristics, such as zip code 70xxx-71xxx areas where the amount of loss has little to do with the number of catastrophes. In this case, regression is not effective, and it is even more unreasonable to apply the national model (because annual premiums with a high number of disasters will be charged too much), and it may be more reasonable to charge a fixed premium regardless of the number of disasters.

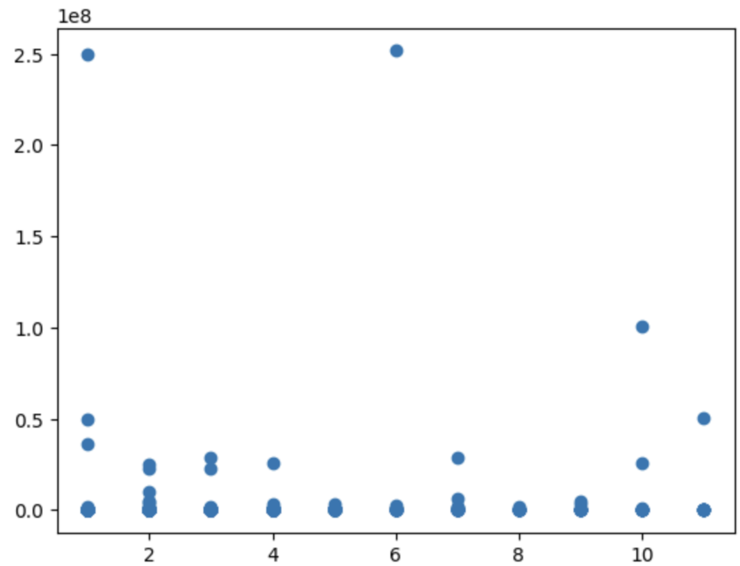

Figure 12: The Analysis of Louisiana

Since regional policies are fraught with uncertainty, let's compare Louisiana and Texas specifically. Texas's overall Damage Cost reaches nearly 4.5 times that of Louisiana's, and Clusters 1, 2, and 3 all show up in some quantity, although it's still 2 that makes up the bulk of the total, while there's virtually no Cluster 3 presence in Louisiana. However looking for connections between the two states we can also find certain patterns; Cluster 2 is dominant in every state, Cluster 1 is second, and Cluster 3 is all but absent. After summarizing the above differences and patterns we can conclude our model.

Insurance companies should adjust their pricing, in addition to the fixed cost that every region should have, when allocating the proportional distribution of letters between clusters in the ratio of Cluster 2 >Cluster 1 >Cluster 3, and increase this aspect of collections in Texas by a factor of 4.5. Then we are going to consider the population. In Texas, the population is estimated to be about 6,654,774 people. This represents a growth of 0.8% from the previous year. While in Louisiana, the population is projected to be approximately 4,690,730 people, which indicates a smaller growth rate of 0.44% compared to the previous year. These figures highlight that Texas has a significantly larger population than Louisiana, and it's also experiencing a slightly higher growth rate. With better prospects, the company can appropriately lower its pricing in Texas to have a larger customer base.

4.2 Economic Model

The insurance services involve multiple stakeholders, so apart from the risk assessment, we believe it is also valuable to conduct the **cost-and-benefit** analysis using **Game Theory**.

4.2.1 Assumptions

To simplify our model, we restricted the stakeholders to only involve the **insurance company** and the **client (as individual)**. In other words, we **will not consider the company's competitors** and **will not analyze the whole customer base** in this model.

Considering the abnormal natural disaster circumstances, we came up with the following assumptions:

- There will be less, **no asymmetry information** among the two agents provided that big natural disasters will be informed to all agencies in the economy
- Since the disasters closely relate to necessity of human life, we would assume that the insurance companies will behave morally. In other words, **no adverse selection or moral hazard** will be considered in our model

Following the above assumptions, we clarified how insurance functions and analyzed the **rational behaviors** of the two agents as below:

- The client wants to buy insurance to secure their properties
- The client want to save the money that they pay on premiums
- The client prefer more holistic coverage especially under special circumstances like natural disasters
- The company wants to maximize its profits by raising the premiums and lowering the payoffs
- The company is likely not willing to provide coverage given higher risks

4.2.2 Normal-Form Game Theory

According to our assumptions, we believe a **Normal-Form Game** will be enough to model the insurance service.

Behaviors

1. The Insurance Company
   - Not underwrite the policy
   - Underwrite the policy
2. The Client
   - Buy the insurance
   - Not buy the insurance

Provided the above behaviors, we defined the payoffs of the action of **underwriting policy** into the 4 scenarios. To recall, the client in our model refers to an individual, not the whole client group.

The payoffs are to the scale from -5 5 with 5 representing the most benefits and -5 representing the most costs.

Payoffs

1. The company underwrites the policy and the client buys the insurance. In this case, the company gains premiums and the client's property is secured, so we scale it to be (3, 3), or mutual benefit.
2. The company underwrites the policy; yet, the client does not buy the insurance. In this case, the company loses this client and the property is not secured. We scale this to be (-5, -3), and this scenario is worse for the company since it takes the action and hence has the opportunity cost.
3. The company does not underwrite the policy and the client still buys the insurance. In this case, the company gets the premiums and the client's property is secured, so we scale it to be (5, 3). The company gains more than the first situation because it does not take the opportunity cost of rewriting the policy.
4. The company does not underwrite the policy and the client does not buy the insurance. In this case, the deal does not matter to both agents, so we simply scale it as (-1, -1) provided that the unsuccessful deal harms both sides a little.

We visualized the Payoffs as below:

Visualization Symbols

- Insurance Company: IC
- Client: C
- Buy Insurance: BI
- Not Buy Insurance: NBI
- Underwrite the Policy: UP
- Not Underwrite the Policy: NUP

Game Theory Table Representation

IC/C	**BI**	**NBI**
UP	(3, 3)	(-5, -3)
NUP	(5, 3)	(-1, -1)

Conclusion: From the above table, it is clear that no matter the insurance company underwrites the policy or not, the client will always likely to buy the insurance, so the game theory concludes that **there is no need to underwrite the policy**.

4.2.3 Further Improvements on Game Theory

In our current model, while we hold the assumption that in the face of natural disasters, there exists a symmetry of information and a moral standard of behavior within the insurance sector, this perspective may be overly simplistic. Our model's framework, which primarily considers just two agents, may not adequately capture the complexity and dynamics of real-world scenarios. This simplification could potentially skew our conclusions, as the interactions in the insurance market are far more intricate, involving multiple stakeholders with varying interests and behaviors.

To address this limitation, we suggest that future research should adopt a more comprehensive approach. Specifically, a more complex Game Theory model that includes a broader spectrum of participants, such as multiple insurance competitors and a diverse client base, would provide a more accurate representation of the market dynamics. This expanded model would allow for the examination of various strategic interactions among different insurance providers and their clients, offering insights into competitive behaviors, market responses, and customer choices in the context of natural disasters. Implementing such a model would not only enhance the robustness of our findings but also enable a more nuanced understanding of the insurance market's mechanics. This, in turn, could lead to more effective strategies for risk management and decision-making in the face of natural disasters, benefiting both insurers and policyholders alike. Thus, a more intricate and detailed Game Theory model is crucial for a deeper, more accurate analysis of the insurance sector's response to natural disasters.

5 Model II: Preservation Model

After analyzing the clusters and visualizing the impact of natural disasters. Our model could also be adapted to suggest new sites for real estate companies to invest on. The clusters with less risks would be the ideal continents to construct new sites. But what about the already existing archaeological sites? There are historical instances where people moved the valuable sites to face natural disasters, so there is a trade-off to whether preserve the sites landed on endangered continents or not. Motivated by this, we have come with a preservation model.

There are several considerations apart from the previous Insurance Model:

1. **Assessment and Monitoring:** Regular assessment of the structural integrity and condition of the site, using advanced technologies like satellite imagery, drones, and IoT sensors.

2. **Preventive Conservation:** Implementing measures to prevent or minimize future damage, including environmental control, erosion prevention, and visitor management.

3. **Restoration and Repair:** Conducting necessary restoration work using traditional methods and materials to maintain the site's authenticity, along with modern conservation techniques.

4. **Cultural Heritage Management:** Policies and practices to manage the site in a way that respects its historical and cultural significance, including local community involvement and traditional knowledge preservation.

5. **Educational and Community Engagement:** Programs to educate visitors and the local community about the site's history and cultural importance, fostering a sense of ownership and responsibility towards its preservation.

Thus, we firstly apply the Insurance Model set above. Then we use a linear model of cultural index and obtained cultural and economical data mainly from the UNESCO.

Our main model is calculated as:

$$\text{CULTURAL INDEX} = \alpha e + \beta c + \gamma h$$

where α, β, γ are coefficients and e, c, h represent a site's/region's economic, cultural, and historical performance.

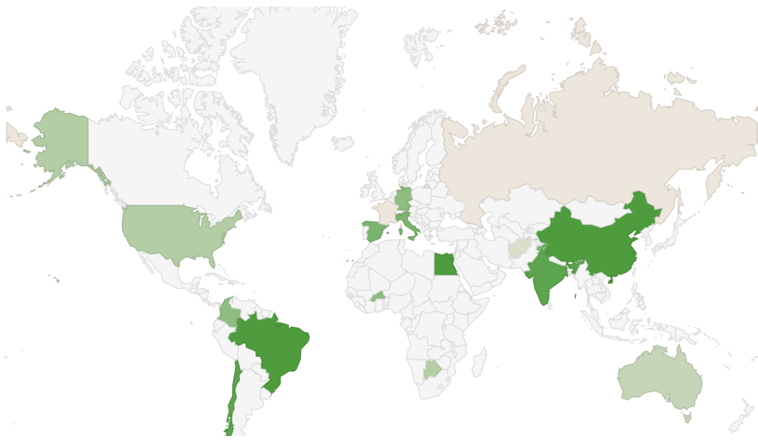

Figure 13: Geomap of the World

We made a color map using **geomap** based on regions as shown in Figure 13.

Therefore, when considering whether or not preserving an archaeological site, we suggest to put efforts on the regions colored in dark green.

6 Sensitivity Analysis

We calculate damage costs related to severe storms and climate change, involving several layers of data processing and modeling. We are going to break down the key elements of our analysis:

1. **Calculation of Damage Cost:** We identified that climate change complicates insurance pricing in disaster-prone areas due to the evolving nature of severe storms. Utilizing Severe Storm Event data from NOAA and BigQuery GIS, we analyze the impact of these events based on geographical patterns and historical data.

2. **Model Formulation:** Our model uses a summation formula to calculate damage costs, taking into account different types of events and their respective coefficients. This approach acknowledges that each event type contributes differently to the overall cost.

3. **Regression Analysis:**

- **Multi-variable Linear Regression:** This method, which incorporates the number of each disaster type and housing quality, seems to provide a fair accuracy in predicting damage costs.
- **Single-variable Linear Regression:** This approach, based on the total number of events, indicates the importance of considering the type of event in addition to its frequency.

4. **Predictive Analysis and Trend Identification:** We attempted to predict future trends by analyzing disaster data over the last 70 years, noticing an exponential growth trend. K-means clustering and regression models are used to predict the relationship between disaster conditions and loss amounts.

5. **Geographical and Event Type Analysis:** We identified that certain storm types and states experience more severe damage than others, likely due to geographic and climatic differences. This leads to targeted analysis focusing on specific states and event types responsible for the most damage.

6. **Machine Learning Model for Risk Assessment:** A machine learning model, specifically k-means clustering, is proposed to categorize zip codes into risk profile clusters based on historical storm data. The model's performance is evaluated using the Davies–Bouldin index and mean squared distance, indicating reasonable accuracy.

7. **State-Specific Analysis:** Further analysis involves examining the impact of storms at a more granular level, like zip codes, in specific states like Texas, California, Louisiana, Georgia, and Florida.

8. **Cluster Analysis and Visualization:** The model's output provides cluster visualizations that indicate different risk profiles for areas within states. This helps in understanding the variance in risk profiles even within a single state.

Our approach of combining historical data analysis with machine learning models provides a comprehensive framework for assessing and predicting the financial impact of severe weather events. It recognizes the dynamic nature of climate change and its varying impact across different geographic locations. The use of advanced statistical methods and machine learning algorithms enables a more nuanced understanding of risk profiles, which is essential for effective insurance pricing and risk management in the face of climate change.

7 Case Study: The Great Wall

7.1 Introduction to the Great Wall

The Great Wall of China, known for its historical and architectural significance, is an extensive ancient defense structure. It embodies a network of walls, cities, barriers, and other defensive features, rather than being just a solitary wall. Originating from the Western Zhou Dynasty, the wall's construction reached a significant phase during the Spring and Autumn and Warring States Periods, though it was relatively shorter then. It was during the Qin Dynasty, under Qin Shi Huang, that the wall underwent major expansions and renovations, famously becoming the "Great Wall of 10,000 miles."

The most extensive work was done in the Ming Dynasty, resulting in the structure most commonly seen today. The wall extends across 15 Chinese provinces and regions, with notable lengths in Hebei and Shaanxi provinces. Comprehensive surveys reveal that the total length of the Ming Great Wall is about 8,851.8 kilometers, while earlier sections from the Qin and Han Dynasties extend over 10,000 kilometers, cumulatively spanning over 21,000 kilometers. Today, the Great Wall encompasses a wide array of cultural relics, including walls, trenches, forts, and other related structures, amounting to over 43,000 distinct segments or locations.

Figure 14: The Great Wall

Throughout its construction, the Great Wall of China utilized a variety of local materials and innovative structural methods. Techniques ranged from rammed earth and mixed brick-stone to using red willow, reeds, and sand in desert regions. Notably, the Western Han Dynasty sections still standing in Gansu and Xinjiang exemplify these early methods. In the Ming Dynasty, advancements in brick-making technology led to increased production, making bricks a common building material. This era saw the extensive use of large bricks for both the inner and outer walls, as well as in the construction of gate arches. Despite the challenges of manual labor and transportation, the uniformity and manageable size of bricks facilitated construction efficiency and quality. The enduring majesty of these structures, particularly the brick arches of the gates, is a testament to the high level of skill in masonry at the time.

For over two millennia since its inception, the Great Wall has been a central figure in cultural interactions between northern and southern China. Its construction, particularly during the Warring States period by King Wuling of Zhao, encouraged north-south exchanges, notably in equestrian and archery skills. During the Qin and Han dynasties, the wall facilitated an unprecedented level of cultural dialogue. Artefacts like the Qin rights and edicts, Han tomb murals in Inner Mongolia and Heringer, and Zhaogun's Tomb bear testament to this cultural melding. The Great Wall region is dotted with historical sites and artifacts, illustrating the depth of these cultural exchanges. Furthermore, since the Han Dynasty, the Great Wall has played a pivotal role in East-West cultural exchanges, particularly through the Silk Road. The wall's enduring legacy is evidenced by its recognition as a UNESCO World Heritage site in 1987, symbolizing its global cultural and historical significance. Throughout history, the Great Wall has inspired countless literary and artistic works, enriching the cultural heritage associated with it.

7.2 Impact of Extreme Weather on Great Wall

Extreme weather has a significant impact on the Great Wall of China. Factors such as heavy rains, strong winds, and extreme temperatures contribute to the erosion and deterioration of the wall's structure. In particular, areas made of rammed earth or less durable materials are more susceptible to damage. The effect of such weather conditions accelerates the wear and tear on the wall, leading to the loss of historical features and necessitating continuous restoration efforts to preserve this iconic monument.

The extreme weather threats include heavy rainfall, which can cause erosion and structural weakening; strong winds, contributing to the deterioration of materials; sandstorms, particularly in desert areas, which can erode and bury parts of the wall; freezing temperatures and snow, leading to freeze-thaw cycles that can damage the masonry; and extreme heat, which can cause expansion and further stress the structure. Each of these weather conditions poses a unique threat to the integrity and preservation of the Great Wall.

Figure 15: The Great Wall is Disappearing

7.3 The Preservation cost of the Great Wall

The preservation of the Great Wall of China is a complex and costly endeavor, estimated to require about 10 million yuan (approximately 1.7 million US dollars) per kilometer. This figure encompasses various aspects of the preservation process, including structural reinforcements to bolster the wall's integrity, the implementation of monitoring systems to track its condition, and the coverage of insurance premiums to mitigate financial risks associated with potential damages.

Given the magnitude of the cost, a diversified approach to funding is proposed. This approach includes seeking support from international organizations like UNESCO (United Nations Educational, Scientific and Cultural Organization) and ICOMOS (International Council on Monuments and Sites), both of which are dedicated to the preservation of cultural heritage sites worldwide. Additionally, the involvement of the State Administration of Cultural Heritage (SACH) in China would be crucial, given its role in managing and preserving Chinese cultural heritage.

Local government grants can also play a significant role in funding, as they often have specific allocations for the preservation of historical sites within their jurisdictions. Furthermore, the engagement of responsible Non-government Organizations (NGOs) that focus on cultural preservation can provide not only financial support but also expertise and advocacy for the conservation efforts.

This multifaceted funding strategy is essential to ensure the sustainable preservation of the Great Wall, considering the scale of the task and the need for continuous maintenance and monitoring to protect this iconic symbol of China's rich historical and cultural legacy.

7.4 Analysis Conclusion Letter of the Great Wall

Beijing
February, 2024
Subject: Preservation Plan for The Great Wall

Dear Northwestern District of China's Residents and Leaders,

I'm writing to you as an expert in the field of insurance risk assessment and historical preservation, with a particular focus on landmarks situated in regions susceptible to extreme weather events. Our attention is currently directed towards the future of our treasured The Great Wall of China, a site steeped in immense historical and cultural value. After conducting a thorough analysis using our specialized insurance and preservation models, I have identified several critical findings that necessitate immediate attention and action.

Our models reveal that The Great Wall faces a high risk of damage, primarily due to seismic activities, floods, and wind erosion. This alarming revelation is not just a matter of concern for the structural integrity of this ancient monument but also poses a significant threat to its historical significance and the safety of the myriad of visitors it hosts. The potential impact of such damage extends beyond the physical deterioration of the Wall; it threatens to erode a piece of our shared global cultural heritage.

While the risks to The Great Wall are significant, they are not insurmountable. Strategic planning, effort, and investment can substantially mitigate these threats. Our approach includes reinforcing the Wall's structure for better resilience against natural disasters, implementing advanced monitoring systems, and developing conservation strategies that honor its historical and contemporary significance.

Prompt and decisive action is crucial to preserve this iconic landmark for future generations.

Recommendation:

1. **Structural Reinforcement:** Immediate reinforcement of the landmark's structure to withstand extreme weather. This involves reinforcing foundations, waterproofing, etc.
2. **Advanced Monitoring Systems:** Installation of weather monitoring systems to provide early warnings for potential weather threats.
3. **Insurance Coverage:** Securing comprehensive insurance coverage to safeguard against potential financial losses due to weather-related damages.
4. **Community Engagement:** Organizing community events to raise awareness and support for the preservation efforts.

Timeline:

- **Phase 1 (Immediate – 6 months):** Assessment and planning secure funding and insurance coverage.
- **Phase 2 (6 – 12 months):** Begin structural reinforcements and install monitoring systems.
- **Phase 3 (1 – 2 years):** Complete all structural modifications. Launch community engagement and awareness programs.

Cost Proposal:

The estimated cost for this project is around **10 million yuan (around 1.7 million dollars) per kilometers**, which includes structural reinforcements, monitoring systems, and insurance premiums. We propose a combination of funding sources, including the United Nations Educational, Scientific and Cultural Organization (UNESCO), International Council on Monuments and Sites (ICOMOS), State Administration of Cultural Heritage (SACH), local government grants, and responsible Non-government Organizations (NGOs).

You may allocate funds for the preservation of the Great Wall necessitates a blend of traditional and modern approaches. This includes sourcing materials and employing artisans skilled in ancient construction techniques, essential for maintaining the authenticity of the site. Concurrently, investment in modern technologies like 3D laser scanning and digital modeling is crucial. These technologies not only aid in detailed assessments of the Wall's current condition but also in predicting and planning for future preservation needs. This dual approach ensures that while the Wall's historic integrity is preserved, it also benefits from the advancements in contemporary conservation science.

The preservation of the Great Wall is as much about its physical structure as it is about its historical and cultural significance. To this end, substantial funding should be directed towards research and documentation. This includes historical studies, archaeological excavations, and cultural surveys to deepen our understanding of the Wall's past. Equally important is the allocation of resources for community engagement programs. Such initiatives could range from educational workshops that disseminate knowledge about the Wall's history to cultural festivals that celebrate its significance.

These programs not only foster a sense of communal ownership but also contribute to the broader goal of cultural preservation.

In line with global sustainability goals, the preservation efforts for the Great Wall should also emphasize eco-friendliness. This includes the use of sustainable materials in restoration projects and the adoption of energy-efficient technologies. Additionally, funds should be allocated for the protection of the natural environment surrounding the Wall, which is integral to its historical context and current appeal. This approach not only aligns with environmental conservation standards but also ensures that the preservation efforts are sustainable in the long run.

This investment is not just in the physical structure of The Great Wall but in preserving a piece of our shared heritage. It is also a proactive step towards ensuring the safety and continued enjoyment of this landmark by future generations. We welcome your thoughts and participation in this essential project. Together, we can protect and cherish The Great Wall for many more years to come.

Sincerely,
ICM Team

8 Model Evaluation

8.1 Strengths

- **Accuracy and Predictive Power:** Our model shows high accuracy in predictions or classifications on validation data.
- **Generalization:** Our model performs well not just on the training data but also on unseen data.
- **Robustness:** Our model handles variability in data and maintain performance under different conditions
- **Efficiency:** The model requires less computational resources for training and prediction, and the running time is acceptable.
- **Interpretability:** Our model offers insights into the relationships and importance of different variables, particularly in fields where understanding the decision-making process.

8.2 Weaknesses

- **Sensitivity to Parameter Settings:** Our model is a little sensitive to the choice of parameters, which may cause potential difficulty to tune and maintain.
- **Complexity:** With many mathematical and computational methods involved, even though it is efficient enought, it can be hard for other people to interpret.

References

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