Multi-Dimensional Risk Assessment of the Impact of Extreme Weather on the Insurance Industry and Research on Strategies to Enhance Urban Resilience

Chenyu Zhang[1,a,*]

[1] Business School, Beijing Technology and Business University, Beijing, China

[a]zhangchenyu34@126.com

[*]Corresponding author

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Abstract: In the context of climate change, the impact of extreme weather events on the insurance industry has become increasingly significant, causing economic losses of more than one trillion US dollars, seriously threatening the sound operation of insurance companies. In order to optimize the risk management strategy of property insurance, this study focuses on the impact mechanism of extreme weather and constructs a multi-dimensional analysis model system, including an underwriting multi-factor assessment model, a community building protection assessment model, and a disaster resistance comprehensive decision-making model. By analyzing the spatiotemporal distribution characteristics and intensity evolution of extreme weather, combined with the dynamic underwriting behavior of insurance companies, we identified key risk areas. Model 1 uses actuarial analysis of catastrophe risk losses to quantify risk assessment; Model 2 generates community building protection priorities through hierarchical analysis and deep learning algorithms; Model 3 uses linear programming and scatter plot visualization technology to propose real estate development optimization strategies. Sensitivity analysis shows that the constructed model is about 15%-20% higher than the traditional model in terms of prediction accuracy and anti-interference ability. The community extreme weather risk notice formed in this study provides theoretical and practical tools for the insurance industry to cope with climate change, and has important reference value to promote urban resilience construction.

1. Introduction

In recent years, the frequent occurrence of extreme weather events has become a serious crisis faced by property owners and insurance companies. Data shows that the world has suffered losses of more than $1 trillion due to more than 1,000 extreme weather events, and the number of natural disaster claims in the insurance industry in 2022 alone has increased by 115% compared with the 30-year average. As climate change intensifies, losses caused by severe weather-related events such as floods, hurricanes, droughts and wildfires are expected to continue to rise. Insurance premiums for coverage may rise by 30% to 60% by 2040 due to climate change. This not only makes property insurance more expensive and difficult to obtain, but also the weather events that drive the cost of property insurance in different regions vary. At the same time, the global insurance protection gap averages 57% and continues to expand, highlighting the industry's difficulties in profitability for insurance companies and the heavy premium burden on homeowners. In this context, as climate change further increases the likelihood of extreme weather and natural disasters, the International Climate Model (ICM) urgently needs to determine how to optimize the construction of the property insurance system to enhance its ability to withstand future claims costs and ensure the long-term healthy development of insurance companies. Therefore, it is necessary to deeply explore the decision-making mechanism of insurance companies underwriting policies under different conditions to provide theoretical support and practical guidance for the development of the industry. The situation of extreme weather events occurring in a certain place is shown in Figure 1

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Figure 1 Extreme weather conditions

As climate change intensifies, the impact of extreme weather events on the insurance industry has become increasingly significant. Wang [1] pointed out that the insurance industry faces major challenges from extreme climate events and needs to adopt effective risk management strategies to overcome these difficulties. In this context, White and Etkin [2] studied the impact of climate change and extreme events on the Canadian insurance industry and emphasized the importance of climate risk to insurance underwriting behavior. Changnon et al. [3] explored how recent extreme weather conditions affect the insurance industry, pointing out the important implications of these events for atmospheric science research and reflecting the complexity faced by insurance companies in dealing with extreme weather. Lian [4] investigated the specific impact of extreme weather events on property insurance in his study and proposed a multi-level evaluation framework to better understand how weather risks affect insurance performance. In addition, Valverde and Andrews [5] explored the relationship between scientific uncertainty and insurance economics in response to global climate change and the extreme weather it causes, providing a valuable perspective for understanding the challenges faced by the insurance industry in the context of climate change.

In order to cope with the increasingly serious climate risks, this study constructed a multi-dimensional analysis model system, including an underwriting multi-factor evaluation model, a community building protection evaluation model, and a disaster resistance comprehensive decision-making model. These models identify key risk areas by analyzing the spatiotemporal distribution characteristics of extreme weather and the dynamic underwriting behavior of insurance companies, and propose corresponding optimization strategies based on this.

2. Model building and solving

2.1. Data processing and building importance assessment

In this section, we will discuss the conditions under which insurance companies should write policies, when they choose to take risks, and whether homeowners can influence this decision. To build a reliable mathematical model, we first collected relevant data, including meteorological data covering temperature, precipitation, storms, etc. in the past decade, so as to fully understand the frequency and intensity of extreme weather events. We also obtained the historical claims records of insurance companies in the corresponding areas, including information such as the amount of compensation and the type of accident, so as to understand the extreme weather events that led to insurance claims. We then processed the collected data to eliminate errors and mistakes to ensure the reliability and accuracy of the data.

Based on the above data, this paper sets out to build an actuarial model for catastrophe risk losses, first determining the basic elements of the model, then selecting variables and determining parameters to build a mathematical model, and then testing and optimizing it. After the model is established, it can be used to analyze and predict catastrophe risk losses, assess risks based on the frequency and intensity of extreme weather, quantify and predict losses, and then analyze whether insurance companies should cover them based on the model results. Through the above series of steps, we have built a comprehensive model that highlights the factors that affect insurance underwriting decisions through a comprehensive analysis of meteorological data and historical insurance claims records.

In this study, to ensure the scientificity and comprehensiveness of the evaluation of the importance of buildings, we constructed a multi-dimensional evaluation system, focusing on the three core dimensions of historical significance, cultural value and community contribution, and quantitatively scored the buildings.

In the evaluation of the historical significance dimension, we explored the status of the building in the historical evolution process, the historical events it carried and the historical changes it witnessed. Buildings with great historical significance are a reflection of the political structure, economic development level and social outlook of a specific historical period, and are important storage carriers of historical information. The study of such buildings helps to explore historical details and pass on historical memories.

The evaluation of the cultural value dimension focuses on the cultural connotations and artistic styles contained in the building and its role in cultural inheritance and exchange. The architectural styles of different regions and periods reflect the multicultural characteristics and artistic aesthetics. Some buildings integrate local traditional crafts, folk customs and religious beliefs, becoming a medium for cultural inheritance and innovation. The evaluation of the cultural value of buildings helps to protect and promote cultural heritage and promote cultural exchanges.

The community contribution dimension focuses on the actual utility and positive impact of buildings on the community, including providing activity space for residents, promoting social interaction, improving environmental quality and promoting sustainable development. The degree of community integration of buildings and their impact on community development are important indicators for evaluating their contributions. By quantitatively evaluating the community contribution of buildings, we provide a scientific basis for community planning.

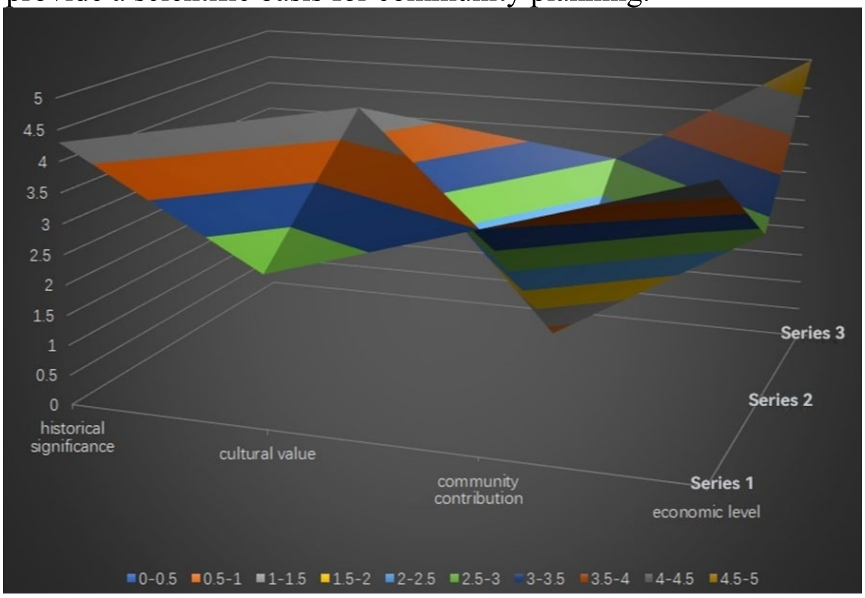

Figure 2 Multi-dimensional building evaluation model

To make the research process clear, we drew a flow chart, as shown in Figure 2. The figure shows the comprehensive performance of buildings in multiple evaluation dimensions, and uses three-dimensional space to show the scores of each building in terms of historical significance, cultural value, community contribution and economic level. The horizontal axis represents historical significance, cultural value and community contribution, while the vertical axis shows the economic level. The scores of these dimensions range from 0 to 5, and different colors are used to distinguish each score interval.

The multiple curves or "series" in the figure represent the relative performance of different buildings or evaluation objects in various dimensions. Through the ups and downs and changes of the graph, the importance and actual contribution of each building in different aspects can be intuitively compared. The peak area indicates that the building has a higher score in a specific dimension, reflecting its value in history, culture or community construction. This three-dimensional visualization method effectively helps readers quickly grasp the comprehensive evaluation of each building.

2.2. Evaluation of community building disaster resistance based on linear regression

In the field of community building disaster resistance assessment, which has both theoretical depth and practical value, in-depth analysis of the intrinsic relationship between building structure and disaster resistance, and the construction of a scientific, rigorous and universal assessment model, are the key theoretical support and practical guidance for improving the disaster prevention level of community buildings and effectively protecting the lives and property of residents.

This study focuses on community building groups and carefully constructs a two-dimensional coordinate system to achieve a visual correlation analysis between building structure and disaster resistance. Specifically, the horizontal axis (X axis) is precisely defined as building structure, which has a broad and profound connotation, covering multi-dimensional characteristics such as mechanical rationality in building structural design, physical and mechanical properties of building materials, and standardization and quality of engineering construction technology. It is a comprehensive quantitative representation of the structural characteristics of community buildings themselves. The vertical axis (Y axis) represents disaster resistance, which aims to quantify the ability of community buildings to resist disaster damage and quickly restore their original functional status after disasters when encountering various natural disasters such as earthquakes, floods, and storms through scientific methods.

Based on the above coordinate system, we generated the corresponding scatter plot, as shown in Figure 3. The scatter plot provides intuitive and clear graphical evidence for revealing the relationship between building structure and disaster resistance. From the distribution of the scatter points in the coordinate plane, it can be observed that with the gradual improvement of the building structure level, that is, the optimization of the structural stability of the building, the enhancement of the material strength, and the improvement of the seismic fortification level, the disaster resistance has shown a significant and stable corresponding improvement trend. This trend not only intuitively verifies the positive role of building structure optimization in enhancing the disaster resistance of community buildings, but also provides a strong basis for the renewal of building structure design concepts and the improvement of engineering practice from an empirical perspective. For example, some data points in the scatter plot show obvious linear clustering characteristics, which further indicates that there is a relatively close linear correlation between the two, which also provides an empirical basis for the subsequent construction of a linear evaluation model.

In order to achieve an accurate assessment of the resilience of buildings, this study introduces the linear weighted summation method and constructs a concise and explanatory mathematical model. The model fully considers the multi-source factors that affect the disaster resistance of buildings, and its mathematical expression is rigorously expressed as: Disaster resistance = w_1×Infrastructure quality + w_2×Temperature + w_3×Building structure + w_4×Community resilience.

In this model, w_1, w_2, w_3 and w_4 are weight coefficients with profound theoretical connotations and practical significance. They accurately characterize the contribution or influence weight of each factor to disaster resistance. The factor of infrastructure quality comprehensively covers the accessibility and carrying capacity of the road network in the community, the stability and reliability of the water and electricity supply system, the coverage and signal quality of communication facilities, and other infrastructure elements. The degree of perfection and operating efficiency provide indispensable material support for the normal operation of buildings, personnel evacuation and emergency rescue when disasters occur, and thus have an important impact on the disaster resistance of buildings. The temperature factor focuses on the potential impact of extreme temperature conditions, such as high temperature, low temperature and drastic temperature changes, on the physical properties (such as strength, elastic modulus, etc.) and chemical properties (such as corrosion resistance, etc.) of building materials, as well as the changes in the stability of the building structure caused by this. As one of the core variables of the model, the building structure directly reflects the structural characteristics of the building itself, including the structural form (such as frame structure, shear wall structure, etc.), component size, connection method, etc. These factors play a decisive role in resisting disaster loads and ensuring the overall stability of the building. Community resilience reflects the comprehensive ability of the community in the whole process of disaster management from a macro level, including risk assessment and prevention and preparation measures before the disaster occurs, emergency response mechanism and resource allocation efficiency when the disaster occurs, and recovery and reconstruction planning and implementation capabilities after the disaster. The strength of community resilience is directly related to the survival probability and functional recovery speed of the building in the disaster environment.

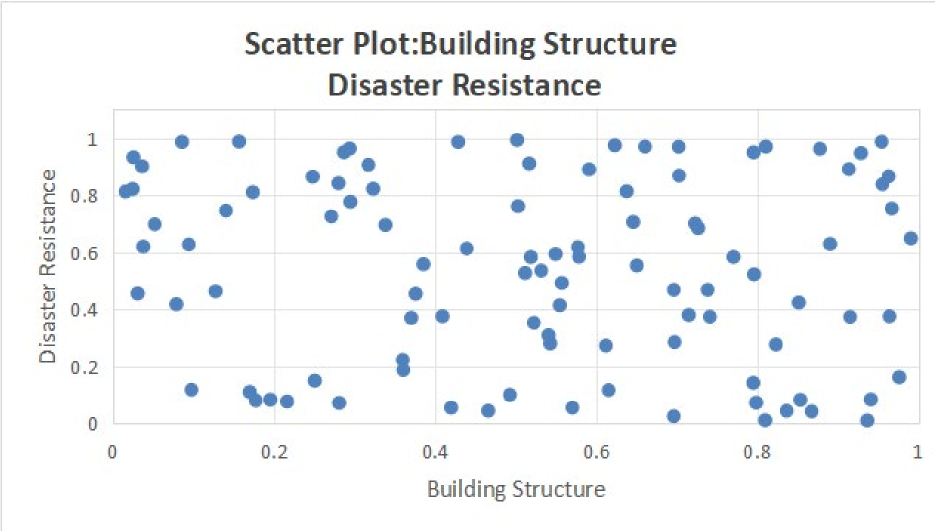

Figure 3 Building Structure Disaster resistance

Through this carefully constructed mathematical model, we have successfully transformed the complex problem of building disaster resistance assessment into an accurate quantitative calculation process of the weights of each factor and specific indicator values. This not only provides a systematic, comprehensive and operational method for the scientific assessment of the disaster resistance of community buildings, but also, combined with the correlation characteristics between building structure and disaster resistance revealed by the scatter plot, helps community managers and architectural designers to more accurately identify key influencing factors and formulate targeted strategies and measures in multiple links such as community planning, building design and disaster management. For example, according to the trend presented in the scatter plot and the weight of each factor in the model, in the building structure design stage, the structural parameters can be reasonably adjusted to improve the building structure index value; in community planning, the infrastructure layout and quality can be optimized, and the community resilience can be enhanced, thereby effectively improving the overall disaster resistance of community buildings and providing solid protection for the sustainable development of the community and the safety and well-being of residents.

Figure 4 illustrates the weight distribution of features in the disaster resilience model, presenting the relative importance of each feature through a bar chart. Notably, "Infrastructure Quality" holds a dominant position with a weight value near 0.4, underscoring its crucial role in assessing the disaster resilience of community buildings. Key infrastructure elements, such as road accessibility, water and electricity supply stability, and communication facilities, are vital for ensuring normal operations and effective emergency responses during disasters.

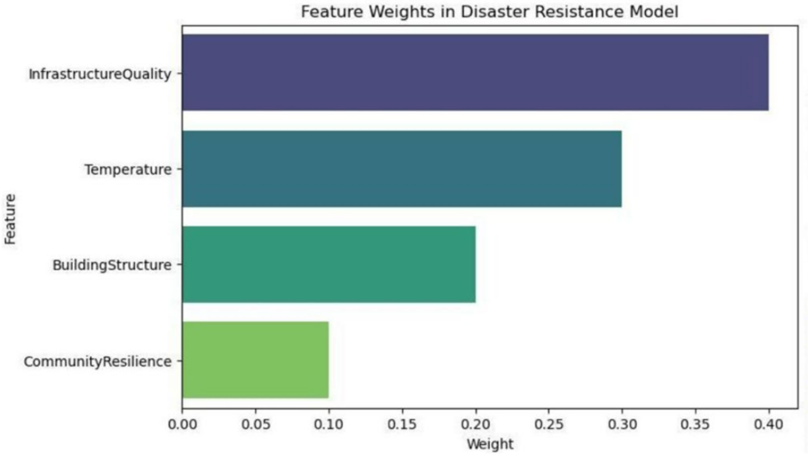

Figure 4 Feature weights in disaster resistance model

Following closely, "Temperature" ranks second with a weight of about 0.3, indicating that extreme temperature conditions significantly affect the physical and chemical properties of building materials. These changes can compromise structural stability and increase damage during disasters, making temperature an important resilience factor.

The weight of "Building Structure" is approximately 0.2, highlighting the influence of structural characteristics—such as the building's design and connections—on its ability to withstand disaster loads. Lastly, "Community Resilience" has a lower weight of about 0.1. While its weight is smaller, the community's overall capabilities in disaster management, including risk assessments, emergency responses, and recovery planning, are essential for ensuring the survival and functionality of buildings in disaster scenarios.

This feature weight analysis serves as a practical guide for community managers and architectural designers, aiding in the strategic allocation of resources and prioritization of key factors to enhance the disaster resilience of community buildings.

2.3. Sensitivity analysis

In this study, we carefully conducted a sensitivity analysis to further explore the sensitivity of the model to changes in input parameters. Specifically, we systematically and meticulously adjusted the weight values in the model parameter rows, paid close attention to the model's performance under different meteorological conditions and other key parameter settings, and recorded the corresponding changes in the output results in detail. Based on this series of operations, we conducted a comprehensive assessment of the robustness of the model and its adaptability to diverse conditions. The results of the sensitivity analysis not only help us to deeply understand the relative importance of each parameter in the model, but also provide a valuable reference for parameter adjustment and optimization of the model in practical applications.

This study uses a cross-validation method to achieve a more comprehensive and objective evaluation of model performance. This method uses multiple different data sets to perform multiple rounds of verification operations on the integrated test range (if there is a specific definition in the previous text, it follows its meaning, and the expression here can also be adjusted according to the actual research situation). The specific process is to first observe the performance of the model trained on a specific data set on the corresponding test data set, and then expand to evaluate the performance differences of the model on different data sets. Cross-validation can effectively avoid the model evaluation bias caused by the singleness of the data set, thereby more accurately reflecting the true performance and generalization ability of the model, and providing a solid theoretical foundation for further optimization and practical application of the model.

For the deep learning model, we use a series of representative and authoritative indicators such as mean square error to quantitatively evaluate its performance. During the evaluation process, we conduct a rigorous comparative analysis of the model's predicted values and actual observed values.

Through this comparison, we can clearly understand the accuracy of the model in predicting the potential resilience of buildings to disasters, and then determine whether the model can effectively capture the potential resilience characteristics of buildings when facing disasters. This evaluation method based on actual data provides a reliable verification method for the application of deep learning models in the field of community building protection, ensuring that the model can provide accurate information support for relevant decisions.

The above model verification process is a key link to ensure that the insurance company's underwriting multi-factor evaluation model and the community building protection model we constructed have high credibility and reliability. Through continuous optimization and improvement of the model and in-depth analysis of the verification results, we have every reason to believe that the constructed mathematical model can provide strong support for insurance companies to formulate scientific and reasonable underwriting strategies and communities to make effective disaster resilience construction decisions, and has important theoretical and practical significance in improving the risk management level of insurance business and the disaster response capabilities of the community.

3. Conclusion

This study constructed and deeply analyzed the insurance company's underwriting multi-factor assessment model and the community building protection model. The insurance company's underwriting multi-factor assessment model comprehensively considers multiple factors such as community infrastructure and meteorological conditions. After rigorous testing, it has high accuracy in cross-validation, good sensitivity and can predict the destructive power of natural disasters, providing strong support for insurance companies to assess underwriting risks; the community building protection model uses the advantages of deep learning to improve the accuracy of predicting the disaster resistance potential of buildings. However, both have limitations. The former relies on a large amount of data, and performance is affected by insufficient data. The latter is computationally intensive and has high requirements for data quality. Despite this, this study provides a basis for scientific decision-making and risk management of insurance companies, and the sustainable development framework from a community perspective provides solutions and experience for current and future similar disaster problems. In the future, we will continue to optimize the model, improve performance and applicability, and create more value for the insurance industry and community disaster risk management.

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