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# Analysis and Application of Decision Models Based on Risk Assessment and Insurance Pricing

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**Abstract.** Under the current weather conditions with frequent global changes, insurance companies are facing a more complex and dynamic risk environment. Therefore, effective risk assessment and reasonable insurance pricing strategies are particularly important. This paper establishes a risk assessment decision model and an insurance pricing model. The risk assessment decision model utilises the frequency of local extreme weather events and average losses, combined with interest rates to calculate the present value of expected future losses, in order to assess whether to underwrite insurance in a particular area. It supports insurers' judgement and operations in area underwriting decisions by calculating risk tolerances and risk gaps. The Insurance Pricing Model focuses on setting reasonable insurance rates based on risk levels. It recommends higher premiums in high-risk areas to cope with possible losses and lower premiums in low-risk areas to increase market competitiveness. Using case studies from the US and Africa, the document demonstrates the effectiveness of these models in real-world applications. Using historical data and ARIMA models to predict future losses provides insurers with a scientific basis to help them make sound underwriting and pricing decisions.

**Keywords:** Extreme weather events, underwriting decisions, Interest rates.

## 1. Introduction

In the realm of insurance underwriting, effective risk assessment is crucial for making informed decisions, especially in regions susceptible to extreme weather events like hurricanes, droughts, and wildfires. The Insurance Company Underwriting Decision Model (ICUD) addresses this challenge by integrating rigorous methodologies for risk assessment and strategic pricing. The model's primary goal is to evaluate the financial exposure associated with potential claims in high-risk areas. It achieves this by calculating risk expenditures based on event frequency, average losses per event, prevailing interest rates, and operational costs [1-2]. By quantifying these factors, ICUD provides a comprehensive view of the potential financial impact over a defined period. Moreover, ICUD assesses the insurance company's risk tolerance by considering its current assets and anticipated future revenues. This assessment helps in determining whether the company can comfortably absorb the calculated risks associated with underwriting policies in specific regions.To support these evaluations [3], ICUD utilizes advanced statistical techniques such as the AutoRegressive Integrated Moving Average (ARIMA) model. This approach enables the model to forecast annual indemnity losses accurately across different geographical areas, thereby facilitating proactive risk management. In conclusion, the ICUD model represents a robust framework tailored to address the complexities of insurance underwriting in diverse environmental and economic contexts. By integrating sophisticated risk assessment tools with strategic pricing mechanisms, insurance companies can enhance their operational resilience and profitability amidst evolving risk landscapes. The marginal contribution of this paper is to identify and emphasize the complex and dynamic risk environment that insurance companies are currently facing under the conditions of frequent global climate change, pointing out the critical importance of effective risk assessment and rational insurance pricing strategies. By developing a risk assessment decision model and an insurance pricing model, this paper provides insurers with a systematic approach to meet this challenge. The risk assessment decision model uses the frequency and average loss of localized extreme weather events, combined with interest rates to calculate the present value of expected future losses, to help assess whether to underwrite insurance in a particular region, and to support insurers' judgment and operations in regional underwriting decisions by calculating risk tolerances and risk gaps. The insurance pricing model, on the other hand, sets reasonable premium rates based on risk levels, suggesting higher premiums in high-risk areas to cope with possible losses and lower premiums in low-risk areas to increase market competitiveness. Through case studies in the U.S. and Africa, this paper demonstrates the effectiveness of these models in real-world applications, utilizing historical data and ARIMA models to predict future losses and provide insurance companies with a scientific basis to help them make reasonable underwriting and pricing decisions.

## 2. Risk assessment decision model

### 2.1. Insurance Company Underwriting Decision Model

#### 2.1.1. Calculating the risk underwritten locally

Taking into account the time value of expected losses, we include the interest rate to determine the present value of anticipated future losses [4-5]. The risk expenditure in the nth year is represented by:

$$\boldsymbol{L_n} = \frac{\boldsymbol{F \times D + C_n}}{(\mathbf{1 + r})^{\boldsymbol{n}}} \tag{1}$$

F : The frequency of extreme weather events in the region.

D : Average loss caused by each extreme weather event

r : rate

$C_n$: The nth year operating cost

Therefore, to calculates whether to underwrite in that region for the next n years, the total risk expenditure (TL) for those year is calculated as

$$\boldsymbol{TL} = \sum_{k=1}^{n} \boldsymbol{L_k} \tag{2}$$

#### 2.1.2. Calculate risk tolerance

We categorize the risk-bearing capacity of insurance companies into two components: the company's current assets and the future anticipated insurance revenue. Likewise, we take into account the impact of interest rates on the projected insurance revenue [6-7]. The formula to calculate the anticipated insurance revenue for the nth year is

$$\boldsymbol{i_n = i_0(1 + r)^n} \tag{3}$$

$i_n$ : The total amount of insurance orders in the nth year in the future.

$i_0$ : Total amount of insurance orders in the base year.

So we can get the final risk tolerance（TAi）

$$\boldsymbol{TA}\mathrm{i} = \boldsymbol{A} + \sum_{k=1}^{n} \boldsymbol{i_k} \tag{4}$$

A: Current company liquidity

### 2.1.3. Calculate risk gap（f）

We quantify the risk that insurance companies choose to underwrite in that region with the total expenditure amount, and quantify the company's own risk tolerance with the sum of the company's current total assets and future policy income, so as to facilitate the comparison between the two and facilitate the insurance company to make decisions on whether to underwrite in that region.

$$\begin{gathered} f = TL - TAi \\ TL: \text{Total future expected losses} \\ f: \text{risk gap} \end{gathered} \tag{5}$$

$$\text{Decide to underwrite if } f \leq 0 \tag{6}$$

Within the framework of this risk model, we possess the capacity to meticulously formulate strategies tailored to the unique risk profiles of individual regions, whilst maintaining the agility to accommodate the dynamic risk landscape through immediate strategic modifications. To elucidate, subsequent to the computation of a calamity's likelihood of materializing, it becomes imperative to estimate the concomitant damages; a methodical tactic entails the direct forecasting of the anticipated casualty figures or projected economic impairments for the concerned locality during the designated time span [8].

Accordingly, our methodology incorporates the application of the AutoRegressive Integrated Moving Average (ARIMA) time series model to get the annual prediction of indemnity losses across various geographies.

## 2.2. Insurance Pricing Model (IP Model)

In the event that underwriting is selected, we can enhance profitability by setting future premium prices [9], such as opting for higher premiums in high-risk areas and lower premiums in low-risk areas. Assuming that the insurance company's coverage is financial compensation insurance, the insurance company only needs to assess the premiums and compensation for the region, that is, how much money needs to be compensated in the event of an accident disaster. Considering the probability of the anticipated disaster occurrence and the number of casualties, specific premium policies are formulated based on premiums and compensation costs.

$$P = k + \frac{E}{M} + \frac{N}{M} \tag{7}$$

$$N = \frac{TL}{n \times Member} \times M \tag{8}$$

$$\Rightarrow P = k + \frac{E}{M} + \frac{TL}{n \times Member} \tag{9}$$

E：expected profit target

M: Number of insured persons

k：Basic premium paid by each insured person.

N: Average expected compensation costs

P: Premium unit price

Member：The total population of the area

### 2.3. Model application (select the United States and Africa as examples)

#### 2.3.1. Data collection and preprocessing (The United States)

We have compiled data on the financial losses and casualties incurred by the United States due to extreme weather events from 1980 to 2021, presented in Table 1.

**Table 1.** The number of casualties and losses caused by extreme weather in the United States.

| Name | Disaster | Begin Date | End Date | Cost (Millions of Dollars) | Dea-ths |
|---|---|---|---|---|---|
| Southern Severe Storms and Flooding | Flooding | 19800410 | 19800417 | 2473.8 | 7 |
| Hurricane Allen | Tropical Cyclone | 19800807 | 19800811 | 2012 | 13 |
| Central/Eastern Drought/Heat Wave | Drought | 19800601 | 19801130 | 36573 | 1260 |
| Florida Freeze | Freeze | 19810112 | 19810114 | 1864.7 | 0 |
| Severe Storms, Flash Floods, Hail, Tornadoes | Severe Storm | 19810505 | 19810510 | 1268.6 | 20 |
| … | … | … | … | … | … |
| Hurricane Nicholas | Tropical Cyclone | 20210914 | 20210918 | 1056.6 | 0 |
| Southeast, Central Tornado Outbreak | Severe Storm | 20211210 | 20211210 | 3993.3 | 93 |
| Midwest Derecho and Tornado Outbreak | Severe Storm | 20211215 | 20211215 | 1817.6 | 1 |
| Western Drought and Heat Wave | Drought | 20210101 | 20211231 | 9105.6 | 229 |
| Western Wildfires | Wildfire | 20210601 | 20211231 | 10816 | 8 |

Based on the data in the table, we have summarized the frequency of various extreme weather events, the financial losses caused by each type of extreme weather, and the number of casualties resulting from these weather conditions, as shown in Figures 1, Figure 2, and Figure 3.

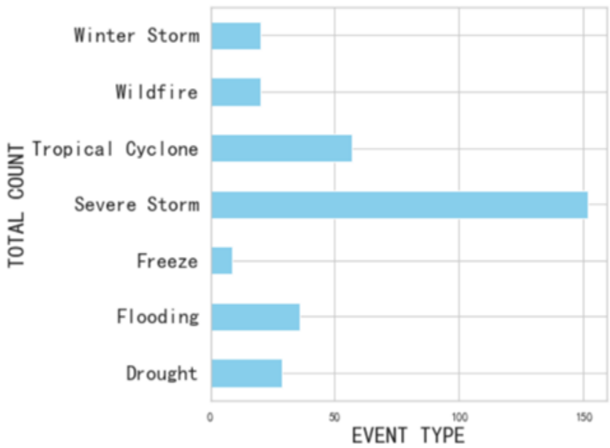


**Figure 1.** Number of occurrences.

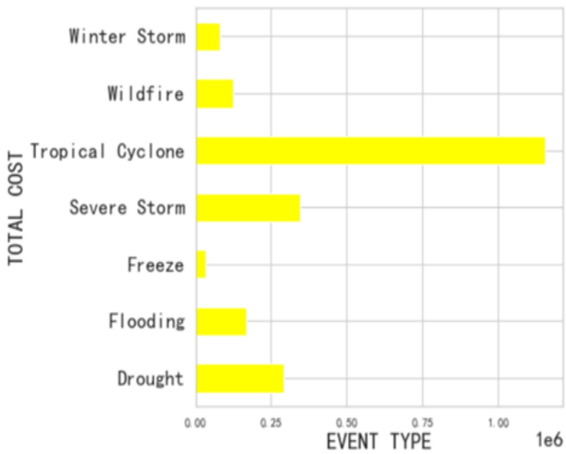


**Figure 2.** Loss caused by the incident.

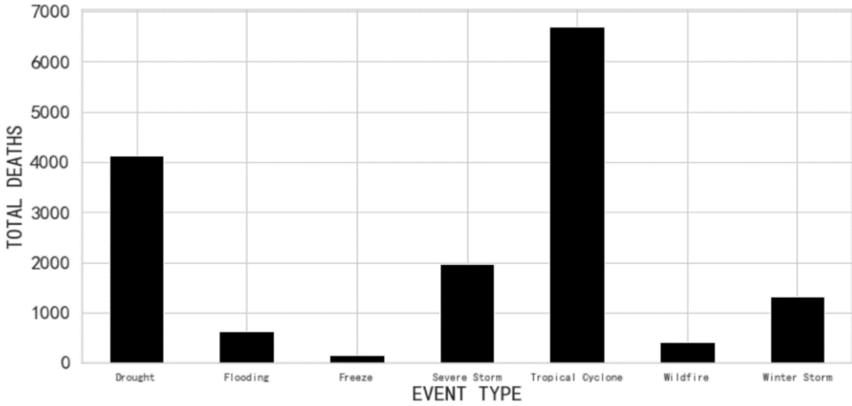


**Figure 3.** Number of casualties in the incident.

As different disasters are intermingled and occur at varying time intervals, to facilitate calculations, we have compiled annual statistics on the number of deaths and total losses, as shown in Figures 4 and Figure 5.

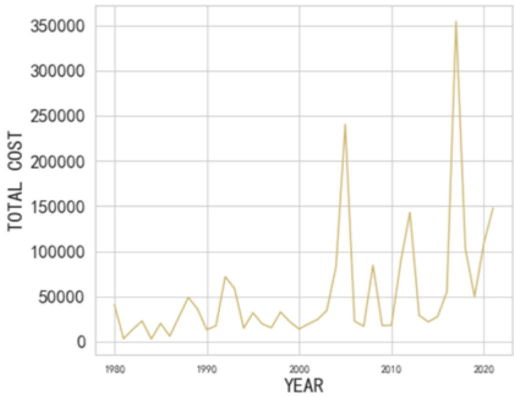


**Figure 4.** The cost number in the correspond year.

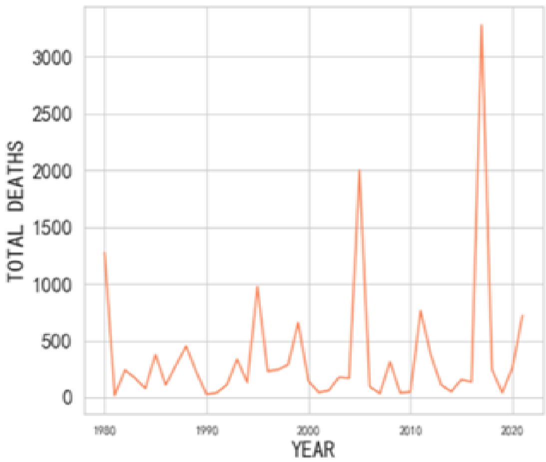


**Figure 5.** The deaths number in the correspond year.

Based on the number of extreme weather events occurring each year, we can derive the frequency of past years.

$$F = 7.69 \tag{10}$$

### 2.3.2. Calculate risks covered locally(The United States)

Forecasting future annual extreme weather losses through ARIMA.

Step One: ADF Test

To calculate the locally underwritten risk based on previous assumptions, we forecast the expected losses for each year, thereby predicting the expected losses over the next seven years. Before employing ARIMA modeling [10], it is essential to analyze and select the right parameters. We commence by performing the Augmented Dickey-Fuller (ADF) test to determine the data's stability. A stable dataset implies that the differencing order is set to zero. Subsequently, we engage in a grid search for Autoregressive (AR) and Moving Average (MA) parameters to identify the most suitable combination. This process enables us to generate a forecast for the ensuing seven years. The results of the ADF test are as follows

$$\begin{cases} \textbf{Test Statistic:} & -4.759697 \\ \textbf{P- value:} & 0.000065 \end{cases} \tag{11}$$

Therefore, we can observe that the test statistic falls below the critical values corresponding to the 1%, 5%, and 10% significance levels. Moreover, the p-value is significantly lower than 0.05, which corroborates the decision to reject the null hypothesis associated with a specific statistical test. Consequently, we conclude that the time series is stationary and set the order of differencing to zero, implying that no differencing is required.

Step two: Determine the remaining parameters of ARIMA through the ACF chart and PACF chart

As Figure 6 illustrates, following an initial lag, the autocorrelation decays towards zero, suggesting that a high order of the moving average (MA) term may not be necessary. Consequently, a value of q=1 was selected. Within the PACF plot, the initial significant autocorrelation is observed at lag 1, indicating that an AR (1) model appears to be a suitable choice, that is, a value of p=1 for the autoregressive component is indicated. After performing AIC computation, the suitability of the (1, 0, 1) model was confirmed. Hence, ARIMA (1, 0, and 1) was chosen for the analysis.

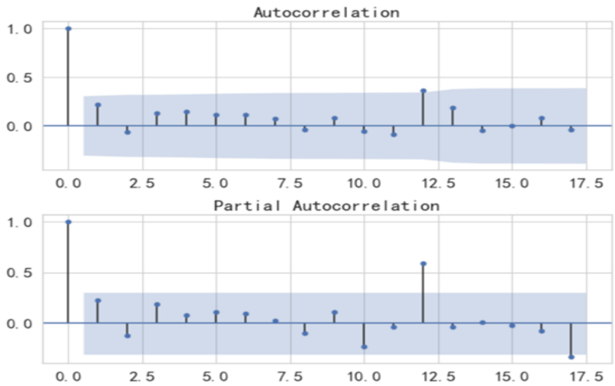


**Figure 6.** PACF.

Step three: Substitute data from previous years into the model

The predicted losses under the influence of extreme weather in the United States in the next seven years are shown in Table 2 and Figure 7.

**Table 2.** Expected losses for the next 7 years in the United States.

| Year | Predictions (Millions of Dollars) |
| --- | --- |
| 2022 | 803265.66122 |
| 2023 | 429128.51097 |
| 2024 | 579832.18238 |
| 2025 | 519128.24918 |
| 2026 | 543579.99260 |
| 2027 | 533730.75014 |
| 2028 | 537698.05731 |

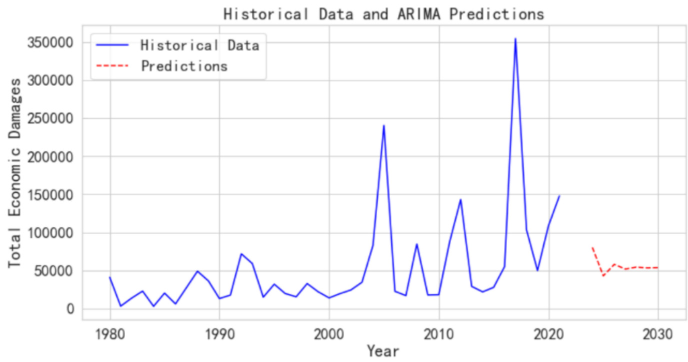


**Figure 7.** ARIMA prediction loss.

We assume that the interest rate level remains basically unchanged. Taking the U.S. 5-year Treasury bond interest rate as an example, let r=5%, and calculate the present value of the total loss in the next seven years.

$$TL = \frac{L_{2022}}{1+r} + \frac{L_{2023}}{(1+r)^2} + \frac{L_{2024}}{(1+r)^3} + \cdots + \frac{L_{2028}}{(1+r)^7} = 3288535.38 \quad (12)$$

### 2.3.3. Calculate risk tolerance

For our analysis, we focused on an insurance company within that area, which reported total assets amounting to $199 million. By examining the company's market share and premium income spanning from 2018 to 2022, we deduced an average annual premium income of approximately $185.19 billion in the United States over those years. Subsequently, taking into account the prevailing interest rate levels, we conducted various financial computations.

$$TAi = 16031094.73 \quad (13)$$

### 2.3.4. Calculate risk gap (The United States)

It's obvious to get

$$f < 0 \quad (14)$$

Therefore, we recommend that in the next 7 years, insurance companies will underwrite coverage in the United States.

### 2.3.5. Premium pricing (The United States)

Calculate expected profit

$$E = R \times T_c \quad (15)$$

R: Capital return target

$T_c$: Total capital

The most recent benchmark interest rate for insurance products has been determined to be 3%, which serves as the benchmark capital return target for insurance companies. To uphold precision, we persist in adopting the company's indicators as numerical references; the company's total asset value amounts to $199,000 Million Dollars. Consequently, the anticipated profit is projected to be 5,970 Million Dollars.

### 2.3.6. Calculate premium

According to data from the U.S. Census Bureau, the U.S. population at the beginning of 2022 is estimated to be about 332,403,650 people, and the number of insured people is about 304,481,743. Assuming that the basic premium is 52 (Dollars) and substituting it into the formula, we can calculate

$$P = 9964.80 \tag{16}$$

Thus, it is recommended that the insurance company sets the actual insurance cost for each person as $9964.80.

### 2.3.7. Model application (Africa )

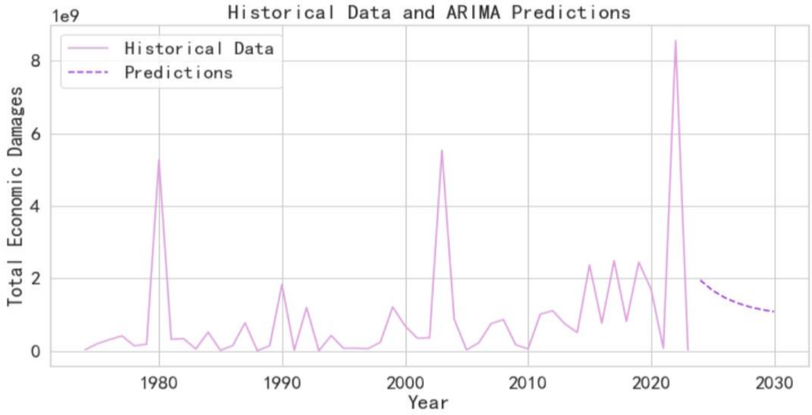


**Figure 8.** ARIMA prediction loss.

ARIMA prediction loss

ARIMA prediction loss is shown in figure 8, similar to the risk gap calculation and premium pricing calculation for the United States, the risk gap in Africa is less than 0. The final premium pricing us get is

$$P = 145.89 \tag{17}$$

That is to say, the insurance company is recommended to set the actual insurance cost for each person to $145.89.

## 3. Conclusions

In conclusion, the Insurance Company Underwriting Decision Model (ICUD) represents a critical advancement in the insurance industry's ability to navigate and mitigate risks posed by extreme weather events and other environmental factors. This model integrates sophisticated methodologies for risk assessment and strategic pricing, serving as a comprehensive framework for insurers to make informed decisions about underwriting policies in diverse geographic and economic contexts. One of the primary strengths of ICUD lies in its ability to quantify and forecast potential financial liabilities associated with extreme weather events. By utilizing formulas that consider the frequency of events, average losses per incident, interest rates, and operational costs, ICUD provides insurers with a clear understanding of the projected risk expenditures over specified timeframes. This capability not only helps insurers prepare financially for potential claims but also supports the establishment of adequate reserves and pricing strategies to maintain profitability and financial stability. Furthermore, ICUD plays a crucial role in assessing an insurance company's risk tolerance. By evaluating current assets and projected future revenues in relation to calculated risk exposures, ICUD helps insurers determine their capacity to absorb potential losses without compromising their financial health. This holistic approach to risk management enables insurers to strike a balance between expanding their market presence and maintaining prudent risk management practices. The application of advanced statistical techniques, such as the AutoRegressive Integrated Moving Average (ARIMA) model within ICUD, further enhances its predictive capabilities. By analyzing historical data and trends, ARIMA facilitates accurate forecasts of indemnity losses across different regions and time periods. This proactive approach allows insurers to anticipate and prepare for future financial challenges, ensuring that they can respond swiftly and effectively to changing risk landscapes. In practice, ICUD empowers insurance companies to make decisions that are not only grounded in rigorous data analysis but also aligned with their strategic objectives and regulatory requirements. By aligning risk assessment with strategic pricing, insurers can optimize their underwriting decisions, offering competitive premiums that reflect the true risk profiles of insured areas. This, in turn, fosters trust and confidence among policyholders while maintaining sustainable profitability for insurance operations.

Looking ahead, the continued evolution and refinement of ICUD will be crucial as insurers face increasingly complex and unpredictable risks driven by climate change and global economic shifts. By continually updating models and integrating new data sources, insurers can enhance their ability to adapt to emerging risks and capitalize on new opportunities in the insurance market.

In conclusion, ICUD represents not just a tool for risk assessment, but a cornerstone of strategic decision-making in the insurance industry. By embracing this comprehensive approach to underwriting decisions, insurers can navigate uncertainties with greater confidence, ensuring resilience and sustainability in an ever-changing world.

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