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Development of Strategic Frameworks for Combating Illegal Wildlife Trade

Huanjun Zu[1,#], Zihang Zou[2,#], Shuning He[1,*]

[1]*School of Materials Science and Engineering, Hebei University of Technology, Tianjin, China, 300401*
[2]*School of Artificial Intelligence and Data Science, Hebei University of Technology, Tianjin, China, 300401*
[#]*These Authors Contributed Equally.*
**Corresponding author: h1437062384@outlook.com*

Abstract: *The illicit wildlife trade represents a significant threat to global ecological balance, contributing to biodiversity loss and destabilizing ecosystems. In the United States, illegal wildlife trafficking has become a pressing concern, demanding the development and implementation of targeted countermeasures. To address this issue, this study proposes a novel framework incorporating advanced algorithms and a comprehensive risk assessment model tailored to the specific contextual factors of the United States. The model is constructed based on five key indicators: political stability, transportation infrastructure, level of digitalization, law enforcement capacity, and public awareness. To ensure the robustness of the index weight distribution, a dual-method approach integrating the Entropy Weight Method (EWM) and the Analytic Hierarchy Process (AHP) was employed. Analytical results indicate that the current risk level of illegal wildlife trade in the United States is 73.6%. To maintain adaptability to dynamic conditions, the study proposes a five-year strategic framework with annual reassessment mechanisms.*

Keywords: *Illegal Wildlife Trade, Combat, EWM-AHP, MLA-BP Neural Network Algorithm*

1. Introduction

Illegal wildlife trade, including unauthorized transactions of rhinos, elephants, tigers, etc., threatens global biodiversity[1]. It involves wildlife products like horns, ivory, bones, and skins used for various purposes. Live trafficking and product processing also fuel this trade. Rooted in profits and cultural practices, it disrupts ecological balances, imperiling species and escalating extinction risks. Understanding its impacts and mitigation measures is vital for environmental, health, and economic security[2].

The United States has established a National Strategy to Combat Wildlife Trafficking, which operates within its borders. The strategy is built on three fundamental components: first, strengthening domestic and international law enforcement efforts; second, reducing the demand for illegally traded wildlife; and third, enhancing strategic priorities for international cooperation. [3].

Based on strategic priorities and relevant research findings, this study has developed a comprehensive framework to address illegal wildlife trade in the United States. Utilizing the integrated EWM-AHP methodology, the study established the IND-IWT model, which facilitates the systematic assessment of risks associated with illegal wildlife trade activities. Additionally, predictive analyses were conducted to evaluate potential outcomes following implementation, thereby ensuring the effectiveness and practical applicability of the proposed framework.

2. Establishment of a Risk Assessment Model for Illegal Wildlife Trade

The data analyzed in this paper are open-source data, sourced from the websites listed in Table 1.

Table 1 Data source

The amount of illegal wildlife trade in the world	World traffic data	The size of the world economy	World level of education
http://www.trafficchina.or	https://sc.macromicro.me/ charts/22281/flight-	https://data.worldbank.org.cn/	https://www.education-progress.org/zh/articles/access

g/world-wildlife-trade-report-executive-summary/	tracking

2.1 Selection of indicators for illegal wildlife trade

Building upon the established framework of illegal wildlife trade dynamics and supported by relevant scholarly literature, this study has developed a comprehensive evaluation system comprising five primary indicators to assess the progression of illegal wildlife trade. These indicators include: (1) political factors, measured through policy quantity and policy intensity; (2) transportation infrastructure, evaluated based on international flight frequency and international parcel volume; (3) economic conditions, assessed using GDP and per capita GDP metrics; (4) information technology development, measured through internet penetration rate and number of internet users; and (5) public awareness, evaluated by education level and enrollment rates. As illustrated in Figure 1, the research framework incorporates two secondary indicators under each primary category, resulting in a total of ten measurable parameters, which collectively enable the systematic assessment of their respective impacts on the expansion of illegal wildlife trade activities.

Level1	Level2	Description	Type
Policy Laws	PI	Number of policies on illegal wildlife trade	—
	NOP	Policy intensity on illegal wildlife trade	—
Traffic	NOIC	Number of international couriers related to wildlife trade	+
	NOIF	Number of international flights related to wildlife trade	+
Degree of informatization	NON	The number of Internet users in the world	—
	IP	World average internet penetration	—
People's consciousness	POPWE	Proportion of the world's population with education	—
	AER	World average enrolment ratio	—
Economic development	GDP	Gross domestic product	+
	GDPPC	Gross domestic productper capita	+

Note:
+: The more benefit indicators,the better
—: The better the lack of cost indicators

Figure 1 Neural network structure

To ensure the relationship between the above indicators and illegal wildlife trade, the research will proceed with a correlation analysis. The research will assess the normality of each factor and use either the Pearson or Spearman correlation coefficient based on the normality.

After conducting the normality test, it was found that the data for each sub-indicator is not normally distributed. Therefore, the research will use the Spearman correlation coefficient to measure the correlation between the factors. The specific calculation of the Spearman correlation coefficient is as follows:

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i}{n(n^2-1)} \quad (1)$$

After the calculation, it was found that each sub-indicator has a strong correlation with the amount of illegal wildlife trade.

2.2 Weight calculation

The research will now use the entropy weight method to calculate the weights of the sub-indicators for each main indicator.

The determination of weights is crucial for evaluating indicators. Therefore, the research uses two weighting models to calculate the weight vector.

The Analytic Hierarchy Process (AHP) is a decision-making method that decomposes elements related to decision-making into hierarchies such as goals, criteria, and alternatives, and conducts

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qualitative and quantitative analysis based on this. This method requires experts to provide a comparison matrix for the main factors.

The Entropy Weight Method (EWM) represents a widely adopted approach for determining indicator weights in multi-criteria evaluation systems. This methodology utilizes entropy values to quantify the degree of dispersion for each indicator within the evaluation framework. A fundamental principle of EWM is the inverse relationship between entropy values and indicator significance: lower entropy values correspond to greater dispersion, thereby indicating higher relative weight and greater influence in the comprehensive evaluation. Conversely, when an indicator demonstrates uniform values across all observations, its entropy value reaches maximum, rendering it ineffective in the evaluation process. Consequently, this study employs entropy values as a quantitative basis for calculating indicator weights, thereby establishing an objective foundation for multi-indicator comprehensive evaluation.

2.2.1 Entropy weight method

(1) Normalization of indicators

The indicators the research has chosen include both extremely high and extremely low values, and they have different units, which can indeed have an impact on the model. To ensure the dimensions of the indicators are the same for implementing the entropy weight method, the research has provided different data processing methods. The larger the value, the more likely illegal wildlife trade is to occur.

(2) Normalization of the maximum value

For indicators such as Internet penetration rate, number of internet users, number of international flights, and volume of international express delivery, which are conducive to the occurrence of illegal wildlife trade, the method of maximum normalization can be used.

$$f(x) = \frac{x}{x_{max}} \tag{2}$$

(3) Minimum normalization

For indicators such as number of policies, policy strength, education level, and enrollment rate, which are not conducive to the occurrence of illegal wildlife trade, the method of minimum normalization can be used.

$$f(x) = 1 - \frac{x}{x_{max}} \tag{3}$$

(4) The entropy weight method is used to calculate the weights of each indicator in the model

The entropy weight method is a method that uses the laws of the data itself to objectively allocate weights. First, the information entropy of each indicator is calculated:

$$e_j = -\frac{1}{lnn}\sum_{i=1}^{n} p_{ij} ln(p_{ij}) \tag{4}$$

In the equation, e_j represents the information entropy of the j-th indicator, p_{ij}represents the weight of the i-th data in the j-th indicator, and n represents the number of data points. To calculate the information utility values and normalize them to obtain the weights[4].

$$\begin{aligned} d_j &= 1 - e_j \\ W_j &= \frac{d_j}{\sum_{j=1}^{m} d_j} \end{aligned} \tag{5}$$

Thereinto, d_j is the information utility value of the j-th indicator, w-j is the corresponding weight of the j-th indicator, and m is the number of indicators. The results are as shown in the following Table2.

Table 2 Weight Distribution of Key Indicators

Economy	Politics	Degree of informatization	Popular awareness	Traffic
Global GDP: 0.042	Number of policies:0.018	Internet penetration:0.067	Proportion of the population with education:0.119	Number of international flights:0.11
Global GDP per capita:0.082	Policy intensity:0.169	Number of netizens:0.09	Average enrolment ratio:0.09	Number of international couriers:0.102

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2.2.2 Entropy weight method

(1) Comparison of Votes

Three experts conducted pairwise comparisons of the impact of five primary indicators on illegal wildlife trade. The results are as follows: Political > Transportation > Awareness > Information Technology > Economy According to the experts' votes, the political factor has the highest impact on illegal wildlife trade, followed by transportation, awareness, information technology, and finally, the economy.

(2) Calculation of Comparison Matrix

Based on the previous discussion and reference table, the research has obtained a comparison matrix.

$$\begin{array}{cccccc} & F_1 & F_2 & F_3 & F_4 & F_5 \\ F_1 & 1 & \frac{1}{3} & \frac{1}{5} & \frac{1}{7} & \frac{1}{9} \\ F_2 & 3 & 1 & \frac{1}{3} & \frac{1}{5} & \frac{1}{7} \\ F_3 & 5 & 3 & 1 & \frac{1}{3} & \frac{1}{3} \\ F_4 & 7 & 5 & 3 & 1 & \frac{1}{3} \\ F_5 & 9 & 7 & 5 & 3 & 1 \end{array} \tag{6}$$

(3) Consistency Testing

Through calculations, the research obtained the eigenvalues and eigenvectors of the matrix, and used the maximum eigenvalue of the matrix to perform consistency testing. If CR < 0.1, it can be considered that the consistency of the judgment matrix is acceptable; otherwise, the judgment matrix needs to be adjusted.

$$CR = \frac{CI}{RI} \tag{7}$$

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{8}$$

Among them, when n=5, RI=1.12. The research obtained R=0.032<0.1. Therefore, the research considers this matrix to be acceptable.

(4) Calculate the weights

After the consistency test, the research obtained the weights of each main indicator through the eigenvector of the maximum eigenvalue of the matrix: policy (0.4816), transportation (0.283), public awareness (0.142), degree of informatization (0.0746), and economy (0.0188).

2.2.3 AHP-EWM Weight combinations

Using the principle of minimum relative entropy, the research established a relevant optimization model to minimize the relative deviation between the AHP and EWM results.

$$\min \sum_{j=1}^{n} w_j(\ln w_j - \ln \alpha_j) + \sum_{j=1}^{n} w_j(\ln w_j - \ln \beta_j)$$
$$\text{s.t.} \begin{cases} \sum w_j = 1 \\ w_j > 0 \\ j = 1,2,\dots,n \end{cases} \tag{9}$$

By using the Lagrange multiplier method to solve the above optimization problem, the research obtained the final weights as follows:

$$w_j = \frac{(\gamma_j \alpha_j)^{0.5}}{\sum_{j=1}^{n} (\gamma_j \alpha_j)^{0.5}} \tag{10}$$

2.3 Project development

Through the analysis of national governments, the research has selected United States governments as the targets for the implementation of our projects.

Below are the detailed contents of a five-year plan for combating illegal wildlife trade. The plan aims to reduce the scale of illegal wildlife trade, protect wildlife and their habitats, through measures such as policy advocacy, law enforcement, public education, and international cooperation.

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Using the EWM-AHP model, the research calculated that the risk of illegal wildlife trade in the United States was 73.6%. Year 1:

Measures:

- Formulate and update laws and regulations related to illegal wildlife trade, including increasing penalties and strengthening law enforcement.

- Engage in cross-border cooperation and establish an information-sharing mechanism on illegal wildlife trade between China, the United States, and New Zealand.

- Carry out public awareness campaigns to raise public awareness and attention to illegal wildlife trade.

Expected outcomes:

- The updating of policies and regulations and the establishment of cross-border cooperation will provide a legal and cooperative foundation for future efforts to combat illegal trade.

- Public awareness campaigns will increase public understanding of illegal trade and promote collective opposition to it.

Year 2:

Measures:

- Strengthen border inspections and monitoring to block transportation channels for illegal wildlife trade.

- Implement wildlife conservation area management plans to enhance monitoring and management capabilities of protected areas.

- Continue public education activities to encourage community participation in combating illegal wildlife trade.

Expected outcomes:

- Strengthening border inspections and monitoring will effectively block transportation channels for illegal trade, reducing the scale of trade.

- Implementation of conservation area management plans will enhance the management capabilities of wildlife protected areas, reducing the occurrence of illegal trade.

Year 3:

Measures:

- Continue to strengthen law enforcement efforts to increase efficiency and frequency of combating illegal trade.

- Support alternative economic development to provide legal economic opportunities for local residents, reducing the motivation for engaging in illegal trade.

- Conduct scientific research to gain in-depth understanding of the factors and trends of illegal wildlife trade.

Expected outcomes:

- Strengthening law enforcement efforts will improve the efficiency of combating illegal trade, reducing the scale of trade.

- Alternative economic development will reduce the motivation for local residents to engage in illegal trade and promote its reduction.

- Conducting scientific research will provide scientific basis for the formulation of subsequent protection strategies.

Year 4:

Measures:

- Continuously carry out public awareness campaigns to further raise public awareness of illegal wildlife trade.

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- Strengthen international cooperation to jointly combat illegal trade with other countries and international organizations, establishing a global regulatory mechanism for illegal wildlife trade.

Expected outcomes:

- Continuous public awareness campaigns will further raise public awareness of illegal trade and form a broad consensus among various sectors of society.

- Strengthened international cooperation will establish a global regulatory system for illegal wildlife trade, jointly addressing the challenges posed by illegal trade.

Year 5:

Measures:

- Summarize and evaluate the effects and achievements of the project implementation in the first four years, adjust and optimize project strategies accordingly.

- Strengthen monitoring and evaluation, continuously monitor the scale and trends of illegal wildlife trade, and evaluate the long-term impact of the project.

- Continue public awareness campaigns and international cooperation to maintain a high level of attention and sustained efforts to combat illegal trade.

Expected outcomes:

- Summarizing and evaluating the effects of project implementation in the first four years will provide a basis for adjusting and optimizing subsequent protection strategies.

- Continuous monitoring and evaluation will provide scientific data support for long-term conservation efforts.

- Continued public awareness campaigns and international cooperation will maintain a high level of attention and sustained efforts to combat illegal trade.

3. Results

3.1 Measure the results of the project

To measure the impact of the project, the research first selected the BP-MLA algorithm to establish the PI-IWT model, which predicted the volume of illegal wildlife trade and the number of cases before and after project implementation. To highlight the project's effectiveness, the research used both intervention analysis models and BP neural networks to determine the specific impact of the project intervention, making our results more intuitive and credible.

3.2 Establishment of the PI-IWT model

First, the research needs to determine the normality of each factor and measure the correlation between factors using either Pearson or Spearman correlation coefficients based on their normality. In Task 1, the research has already tested the correlation between ten indicators and the volume of illegal wildlife trade.

The results show that policy intensity, policy quantity, internet penetration rate, internet quantity, average enrollment rate, people's education level, and the volume of illegal wildlife trade and the number of illegal wildlife trade cases are significantly negatively correlated. The number of international flights, the number of national express deliveries, global GDP, global per capita GDP, and the volume of illegal wildlife trade and the number of illegal wildlife trade cases are significantly positively correlated[5].

After obtaining the correlation between the three sets of corresponding factors mentioned above, the research established neural networks based on the previous database, as shown in Figure 2, including:

1) A neural network between the ten indicators and the volume of illegal wildlife trade.

2) A neural network between the ten indicators and the number of illegal wildlife trade cases.

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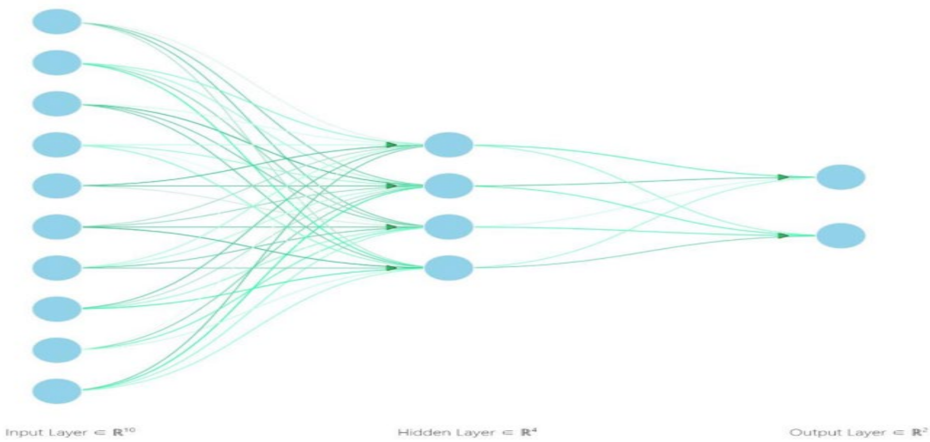

Figure 2 Illustration of the output layer of the neural network

Based on the aforementioned PI-IWT model, the research obtained two sets of corresponding trend changes, as well as the specific values of the volume of illegal wildlife trade and the number of cases before and after project implementation. The results are shown in the following Figure 3 and Table 3.

Table 3 Comparison of power load forecasting of 403 line

Age	Value of IWT	The value of IWT after being affected	Number of cases of IWT	Number of cases of IWT after being affected
2024	288	263	1677	1609
2025	296	224	1801	1496
2026	305	198	1972	1333
2027	320	166	2004	1211
2028	344	136	2014	1007

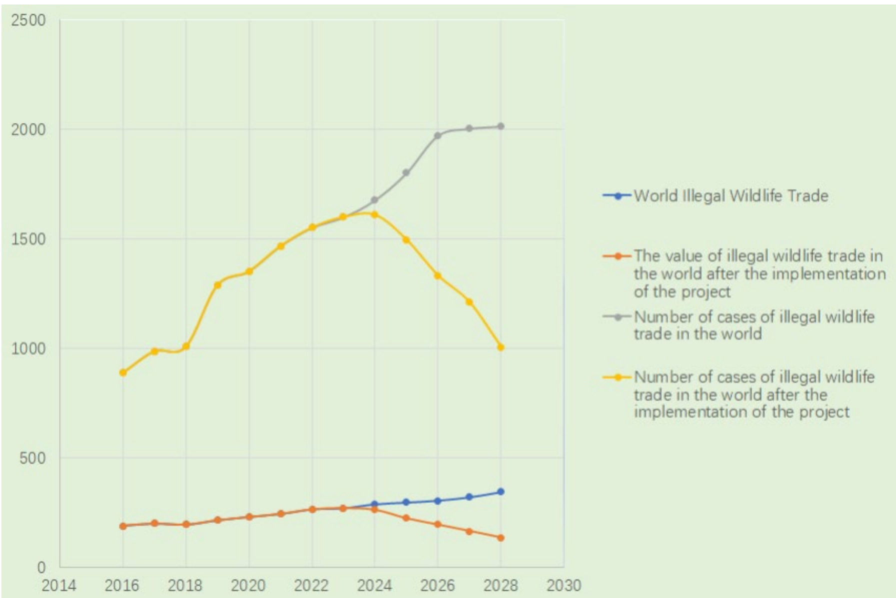

Figure 3 Trend of results

In order to measure the impact of the project, the research has constructed an intervention analysis model to determine the specific effects of the project.

The intervention project is gradually starting and will be sustained in the long term.

4. Conclusions

This study develops a risk prediction model for illegal wildlife trade utilizing the integrated EWM-

AHP algorithm, with the United States as the primary case study. Through comprehensive data analysis, the model estimates the current risk level of illegal wildlife trade in the United States at 73.6%. Building upon this assessment, a five-year intervention framework was designed, incorporating actual case studies. The implementation outcomes were analyzed using MLA-BP neural networks, revealing a substantial reduction in illegal wildlife trade incidents following the project's implementation.

However, the study acknowledges certain limitations, primarily stemming from data constraints and the complexity of real-world operational environments. These factors may influence the practical implementation and effectiveness of the proposed framework. Consequently, addressing illegal wildlife trade requires continuous adaptation to operational realities, with ongoing adjustments based on implementation feedback and evolving circumstances.

Future efforts should prioritize three areas: (1) international data standardization, (2) adaptive predictive modeling, and (3) blockchain-enabled tracking. The integration of real-time monitoring with predictive analytics shows particular promise for preemptive interventions. Success will require sustained political commitment alongside technological innovation, with evaluation metrics incorporating both ecological recovery and trafficking network disruption.

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