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Tourism Sustainability Optimization in Juneau: Integrated Application of Genetic Algorithm and Analytic Hierarchy Process

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Abstract

With the rapid development of tourism in Juneau City, while bringing considerable income to the city, it also brings problems of congestion and retreating glaciers. In order to manage these hidden costs brought by tourism and establish a sustainable tourism industry, this paper based on genetic algorithm, established an optimization model to study the tourism industry. Aiming at the first problem, firstly, a travelable model based on genetic algorithm is established, which determines the objective function by maximizing the total utility. Then, we use curve regression to establish the relationship between social cost and cost and the number of tourists, respectively. In addition, considering the relationship between various factors and existing data, we establish the ecological index and survival index SQ, and assign weights to various indicators by entropy method. Then we use ARIMA to predict the SQ and Env in 2024 based on the data from 2013 to 2023.Then, according to the principle of 3σ, we obtain the constraint condition that Env≥〖Env〗_min=0.197 and SQ≥〖SQ〗_min=0.321. Considering the tourist situation in Juneau, we also use the same limit on the number of tourists that P≤1187782. Finally, the optimal solution is u = 10.886977 (see Table 7). Afterwards, according to the requirements of the topic, we conduct the model, and the results show that the impact of per capita consumption expenditure y on u is relatively limited, and the model is robust. Finally, we use the Analytic Hierarchy Process to compare eleven indicators, and the results show that Standard deviation of glacier area, Gross total (carbon emission), Median Earnings Growth, Unemployment Rate and other indicators have a great impact on the final decision (total income), and they will be used as key factors in the later stage. Aiming at the second problem, this paper applies the tours model based on genetic algorithm to the ancient city, and extends to the scenic spots with few tourists, such as Zhangye Danxia Geopark. First of all, for the ancient city, we collected and processed relevant data, analyzed parameters such as the average consumption expenditure of tourists, and then used genetic algorithm to optimize, and obtained the optimal strategy of the ancient city and the corresponding optimal value as shown in Table 9. Then, we extend the model to Zhangye Danxia Geopark. According to the characteristics of the small number of tourists, appropriate constraints such as ecological index, survival index and number of tourists are used to maximize the total utility. Finally, we get the tourism strategy which is suitable for Zhangye Danxia Geopark. In response to Question 3, we wrote a memorandum for the Juno City Tourism Committee. Through ecological indicators and survival indexes, we proposed that tourism can be realized from the aspects of tourist management, strengthening infrastructure construction, scenic spots and protection, ecology and protection, and policies and regulations. Our model can not only provide scientifically effective policy support for Juneau City but also be generalized to other cities affected by tourism.

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Keywords

Genetic Algorithm; Analytic Hierarchy Process(AHP); Entropy Weight Method (EWM); Sustainable Development; Autoregressive Integrated Moving Average(ARIMA).

1. Introduction

Juneau, officially the City and Borough of Juneau, is the capital of the U.S. state of Alaska, located along the Gastineau Channel and the Alaskan panhandle. The glacier is Juneau's most iconic tourist destination, attracting thousands of visitors annually. Unfortunately, due to the effects of global warming, the glacier's melting rate has significantly increased, raising concerns about its long-term preservation and the future of tourism in the area. Rates of area shrinkage were 5 times faster from 2015–2019 than from 1979–1990. [1] Local residents are deeply concerned about the potential loss of the glaciers, a vital natural landmark that supports the local tourism industry. Some measures concerning this should be taken into account.

2. The Description of the Problem

2.1. Current Situation

Juneau, a small city in the U.S. state of Alaska with a resident population of 30,000, has hosted 1.6 million cruise travelers in 2023 due to its well-developed cruise tourism industry. These visitors contributed about $375 million to the local economy. However, the sheer size of the tourist population also raises issues related to overcrowding, which needs to be addressed by limiting the number of visitors. In addition, Juneau's iconic natural landscape, the Mendenhall Glacier, is rapidly receding due to global warming (partly related to over-tourism). Since 2007, the glacier has retreated a distance equivalent to the length of eight standard soccer fields, raising concerns that future tourism could be severely impacted by the loss of the attraction.

2.2. Environmental and Social Challenges

First, environmental pressures, where local infrastructure is under enormous pressure, such as pressure on drinking water resources, problems with garbage and waste disposal, and carbon emissions caused by tourists. The second is social: local residents suffer from rising housing costs and reduced space, as well as noisy living conditions. Dissatisfied with the status quo, some residents have chosen to leave Juneau or have called for a reduction in the number of tourists. Other residents who make their living from the tourism industry are concerned about reduced income. Finally, current measures include increasing hotel and tourist fees, limiting the number of daily visitors, reducing the sale of alcohol, and using tax revenues for environmental protection, infrastructure improvements, and community projects.

2.3. Problem Restatement

For problem one, we need to model a sustainable tourism industry for the city of Juneau, considering relevant factors such as the number of tourists, local income and some measures to safeguard tourism, and giving the factors we optimize and those that act as constraints and show them through the model, and finally giving a sensitivity analysis and deriving the most important factors.

For problem two, we need to show that our model can be applied to other similar situations. Which measure is most affected by the location effect and how our model can be utilized to strike a balance in scenarios with low patronage.

For problem three, we will write a one-page memo to Juneau's Tourism Commission about our predictions, what the proposed measures would achieve, and suggestions for optimization.

ISSN: 2710-0723

2.4. Problem Analysis

2.4.1. Analysis of Problem 1

Problem 1 belongs to the optimization category and requires a model of sustainable tourism. First, we review relevant information to find data related to over-tourism in the city of Juneau and screen which factors can represent the impact of tourism development. Secondly, we need to analyze the problem from the social and environmental level. Tourism can bring income to local residents and promote economic development, but also bring harm to the environment, so it is necessary to protect the environment as well as ensure the income of residents. Based on the above analysis, we take the total utility maximization as the objective function, and take the total income, environmental protection cost and social cost as the decision variables. Curve regression is utilized to establish the relationship between environmental protection cost and social cost and the number of tourists respectively. In addition, taking various factors into consideration, we established the ecological environment index and the survival quality index using the entropy weight method, and determined the lower limit of the ecological environment index and the survival quality index and the upper limit of the number of tourists according to the 3σ principle. Finally, the social cost, environmental protection cost, ecological environment index, survival quality index and the number of tourists is used as constraints to build the model. For the sensitivity analysis, we change the coefficient y 20 times consecutively with a step size of 10 to check that the model is robust. Finally, we performed AHP hierarchical analysis on eleven indicators related to sustainable development to determine which factors are the most important.

2.4.2. Analysis of Problem 2

For question two, we need to show how our model applies to other places affected by over-tourism, what impact the choice of location has, and the more important measures. For scenic areas with fewer tourists, how should we use our model to achieve a balance. In this problem, we use the planning model from the first question, using new data from Phoenix Ancient Town, and again use genetic algorithms to solve it, and generalize this planning model to scenic areas with fewer tourists.

2.4.3. Analysis of Problem 3

We created a poster as a memo to the organizing committee with our predictions for the future and some suggestions for sustainable development.

The flowchart is as follows:

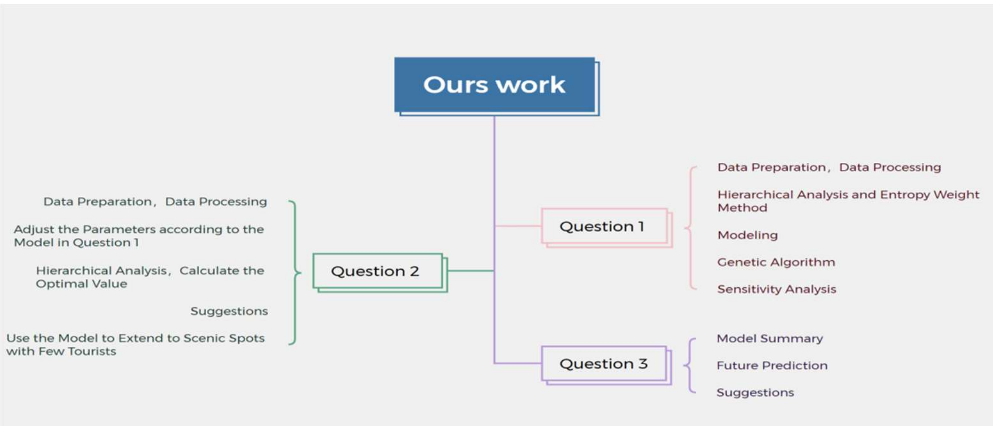

Figure 1. Our work

ISSN: 2710-0723

3. Assumptions

Linear relationship between number of tourists and revenue

It is assumed that the number of tourists has a linear relationship with tourism revenue, i.e., for every additional tourist, tourism revenue will increase by a fixed value accordingly. This assumption is based on the stability of tourists' consumption behavior, which assumes that the average consumption level of each tourist remains relatively stable and does not fluctuate significantly when the number of tourists changes.

Environmental costs have a quadratic relationship with the number of tourists

When the number of tourists exceeds a certain threshold, the environmental cost will rise sharply. This hypothesis is based on the sensitivity of the ecological environment index to over-tourism, and it is believed that too many tourists will have a significant negative impact on the ecological environment.

Social costs have a quadratic relationship with the number of tourists

When the number of tourists exceeds a certain threshold, the social cost will rise sharply. This hypothesis is based on the sensitivity of the residents' quality of life index to excessive tourism, and it is believed that the excessive number of tourists will have a significant negative impact on the quality of life of the residents.

Limitations of Infrastructure Carrying Capacity

It is assumed that the infrastructure (e.g., transportation, lodging, etc.) in the City of Juneau has a fixed carrying capacity. Once the number of visitors exceeds a certain range, the visitor experience and quality of life for residents will significantly decline

4. Terms, Definitions and Symbols

Table 1. Symbols and Meanings

Symbol	Definition
Y	Total Income
C	Environmental Protection Costs
S	Social Costs
E_{nv}	Ecological Environment Index
SQ	Survival Quality Index
P	Number of Tourists

5. Models

Basic Model: A Genetic Algorithm-Based Model for Sustainable Tourism

5.1. Data Preprocessing

5.1.1. Data Preparation

We need to develop a model for sustainable tourism development, and in order to represent the way tourism is developed in Juneau, we collected and processed the following data (e.g., Table 1): median personal income growth in Juneau from 2013 - 2022, hotel tax revenues, traveler volume, traffic volume, diesel particulate air average concentration of diesel particulate air pollutants, nitrous oxide concentration, carbon emissions, unemployment rate, standard deviation of glacier acreage.

ISSN: 2710-0723

Table 2. Raw Data

Year	Median Earnings	Hotel tax revenue	Passenger volume	Gross total	Traffic volume	Mean_Concentration_of_Diesel_PM_Air_Pollutant	Annual_Emissions_NitrousOxide_NonBiogenic	Unemployment Rate of a	Standard deviation of	Government spending on environmental protection	" Government infrastructure	Number of occupants
2013	91.03	300	961000	32.10440069	11883	0.226721245	88.437162	4.8	48.81788028	3785000	3785000	32602
2014	94.93	320	983000	32.64696722	11970	0.226721245	143.636	4.7	47.64316456	4862100	4862100	32560
2015	91.03	350	1015000	32.42217606	11394	0.186313446	89.102	4.6	49.69127073	5456000	5456000	32444
2016	90.08	380	1072000	30.9239951	11557	0.186313446	94.466	4.5	54.47508936	5900000	5900000	32456
2017	91.03	400	1151000	31.23976177	11787	0.186313446	99.532	4.9	51.92713782	4896800	4896800	32106
2018	197.03	420	1306000	31.14433085	12040	0.140303293	95.062	3.9	57.4716318	5805000	5805000	32044
2019	98.03	450	1072000	31.26212339	12083	0.140303293	91.784	5.3	55.36525334	2640000	2640000	32038
2020	-52.97	300	1072000	33.17615204	12305	0.052496495	223.5	3.6	64.90054588	250000	250000	31849
2021	65.05	420	1167000	36.30589169	12118	0.052496495	144.828	2.8	44.40662389	250000	250000	31973
2022	305.40	500	1072000	38.05315792	12034	0.083178396	130.226	3.6	43.85452288	800000	800000	31740

Note: Owing to limited data resources, government expenditure on protection of the environment and government expenditure on infrastructure, represented by total government expenditure, are used.

5.1.2. Outliers and Missing Values

We collect data with missing values, which may lead to biased data analysis results, we use mean interpolation to fill in the missing values and improve the quality and reliability of the data. For some outliers, we excluded them or corrected them. For the glacier area data, we calculated the standard deviation of the glacier area to better reflect the changes in glacier area.

5.1.3. Min-Max Normalization

There is a portion of the data that has a large magnitude, which causes the features of these data to have too much influence on the model. By scaling the data to the same range ([0, 1]), we can eliminate the effect of the magnitude and give each feature equal importance in the analysis. The formula for min-max normalization is as follows:

$$x' = \frac{x - max(X)}{max(X) - min(X)}$$

Scale the data to the range [0, 1].

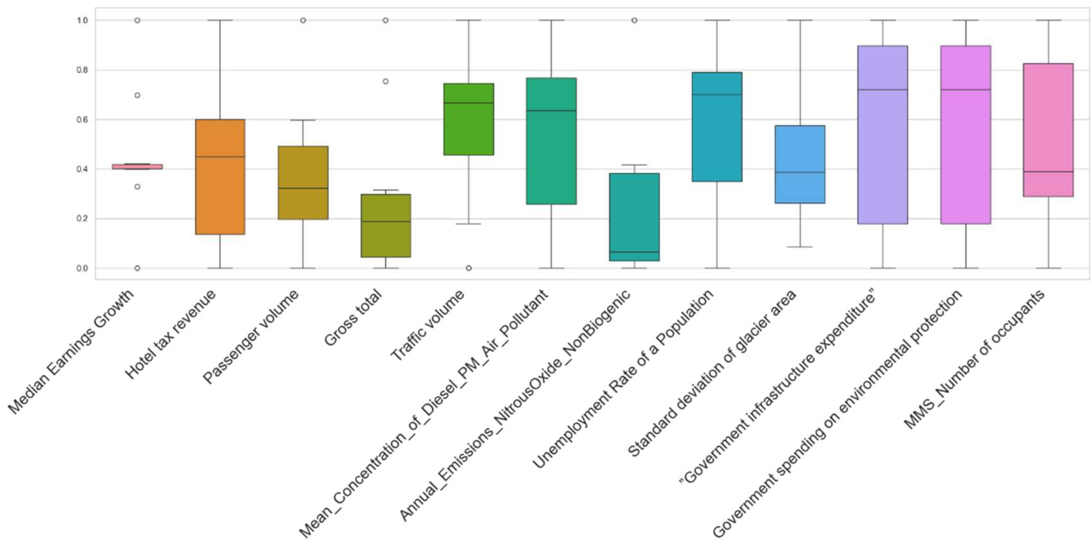

Figure 2. Data after processing

5.2. Hierarchical Analysis and Entropy Method

5.2.1. Hierarchical Analysis

Analytic Hierarchy Process (AHP) is a multiple criteria decision-making tool that has been used in almost all the applications related with decision- making[2]. Hierarchical analysis is a subjective assignment evaluation method as well as a multi-criteria comprehensive evaluation

ISSN: 2710-0723

algorithm, which is commonly used in comprehensive evaluation models. Hierarchical analysis is a simple and practical algorithm that breaks down the elements related to decision making into multiple levels such as objectives, guidelines, and scenarios, on the basis of which qualitative and quantitative analyses are performed. The steps of the hierarchical analysis method are as follows:

(1) Constructing judgment matrix

In the AHP method, the two-by-two comparison of the importance of indicators by experts is a key step. Through this process, a complete judgment matrix can be constructed to quantify the relative importance of each indicator. Based on this, this paper first completes the construction of the judgment matrix to provide support for the subsequent analysis and decision-making.

In this paper, the judgment matrix is noted $\mathrm{C}=\left\{a_{\mathrm{ij}}\right\}_{n*n}$, judging the element of matrix a_{ij} represent the results of the comparison of the importance of the i-th indicator with respect to the j-th indicator, and are satisfied:

$$a_{ij}=\frac{1}{a_{ij}}$$

The specific meanings of the values of a scale of the judgment matrix a_{ij} are given in the following table:

Table 3. contains the values

Scale	Meaning
1	Indicates that the two indicators are of equal importance when compared.
3	Indicates that one indicator is slightly more important than the other when compared.
5	Indicates that one criterion is significantly more important than the other when compared.
7	Indicates that, when comparing two indicators, one indicator is strongly more important than the other.
9	Indicates that one indicator is extremely more important compared to the other.
2,4,6,8	The median value of the two adjacent judgments mentioned above.

(2) Hierarchical single sorting and its consistency test

In view of the existence of the judgment matrix due to any two indicators between the scoring of the importance of different indicators contradict each other, the judgment matrix can be consistency test, so as to effectively avoid this situation.

Only when the judgment matrix passes the consistency test can the calculation continue, otherwise the judgment matrix is modified. Assuming that the maximum eigenvalue of the judgment matrix C is λ , define the consistency index CI :

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

ISSN: 2710-0723

where RI denotes the random consistency index, which varies with n. $CR < 0.1$ indicates passing the consistency test.

(3) Weight calculation

First, each column of the judgment matrix is normalized:

$$a_{ij}^{1} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

The weights are then averaged over the entire matrix to compute the weights $\boldsymbol{w_i}$:

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}^{1}}{n}$$

This gives the vector of weights $w = (w_1, w_2, \ldots, w_{12})^T$.

5.2.2. Entropy Method

Entropy value method is an objective assignment method based on information entropy, which is often used in comprehensive evaluation or decision analysis of multiple indicators. It determines the weights by calculating the degree of data dispersion of each indicator, and the greater the degree of dispersion (i.e., the smaller the entropy value), the more information the indicator provides, and the greater the weights should be. The core idea is to calculate the entropy value of each indicator to determine its weight, thus avoiding the bias of subjective assignment. The entropy value method is as follows:

Data standardization

As the magnitude and order of magnitude of different data may be different, it is necessary to standardize the raw data to eliminate the effect of the magnitude and normalize it using the max-min normalization method.

Calculating the weight of indicators

For the normalized data, calculate the weight of each indicator in each sample $\mathrm{P}_{i,j}$:

$$\mathrm{P}_{i,j} = \frac{x'_{i,j}}{\sum_{i=1}^{n} x'_{i,j}}$$

where $x'_{i,j}$ is the standardized value of the jth indicator for the ith sample; n is the sample size.

Calculating information entropy

Calculate the information entropy for each indicator e_j :

$$e_j = -\frac{1}{\ln(n)} \sum_{i=1}^{n} p_{i,j} \ln(\mathrm{p}_{i,j})$$

Where： $p_{i,j}$ is the weight of the j-th indicator for the i-th sample; n is the sample size; and $\ln(n)$ is the natural logarithm for normalization.

ISSN: 2710-0723

Calculation of the information utility value

The information utility value d_j represents the amount of information provided by the j-th indicator: $d_j = 1 - e_j$.

Calculate weight w_j: $w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$.

Result analysis.

Based on the calculated weights w_j, the importance of each indicator is analyzed. The higher the weight, the greater the impact of the indicator on the overall evaluation.

5.3. Problem 1: Sustainable Tourism Modeling based on Genetic Algorithms

5.3.1. The Foundation of Model

(1) Determine the objective function

Our objective is to maximize total utility (to achieve sustainable development) According to the Cobb-Douglas function, we take the total income, social cost and environmental protection cost as constraints and set the objective function expressed as:

$$max\ u = A_1 Y^{\alpha} A_2 S^{-\beta} A_3 C^{-\gamma}$$

Where u is total utility, Y is total income, C is environmental protection cost, S is social cost, and A1 A2 A3 are model parameters.

We use AHP hierarchical analysis method to give weights to total income, environmental protection cost, and social cost, and get α=0.1638, β=0.539, and γ=0.2973. Considering all kinds of extrinsic factors, let A1=A2=0.1, A3=0.01.

(2) Determine the constraints

1) For Y, let Y=yP, after reviewing the information, we get that the per capita tourism consumption expenditure y is 1708 U.S. dollars.

2) The cost of environmental protection is usually a quadratic function of the number of tourists, set

$$C = a_1 P^2 + a_2 P + a_3$$

Based on the data on the number of tourists and the data on the government's expenditure on ecological and environmental protection from 2013 to 2022, we fit a polynomial regression using curvilinear regression, and get $\boldsymbol{a_1}$=2.005, $\boldsymbol{a_2}$=-1286.7, $\boldsymbol{a_3}$=845.4

3) Similarly, the social cost is usually quadratic with the number of tourists, set

$$S = a_4 P^2 + a_5 P + a_6$$

Based on the data on the number of tourists and the data on government expenditure on infrastructure inputs from 2013 to 2022, polynomial regression was fitted using curvilinear regression to obtain $\boldsymbol{a_4}$= 1.874, $\boldsymbol{a_5}$= -1389.2, $\boldsymbol{a_6}$= 11.025

4) For the ecological environment index $\boldsymbol{E_{nv}}$, set$\boldsymbol{E_{nv}}$=$\boldsymbol{-b_1 CO_2 - b_2 CO - b_3 CH^4 + b_4 C - b_5 P^2}$

Based on the data of Mean_Concentration_of_Diesel_PM_Air_Pollutant, Gross total, Annual_Emissions_Nitrous_Oxide_NonBiogenic and Government_spending on environmental

ISSN: 2710-0723

protection for the period of 2013-2022, we use the entropy method to assign entropy values to the four indicators to obtain the following results. spending on environmental protection data, we use the entropy weight method to assign entropy weight to these four indicators, and get the following results:

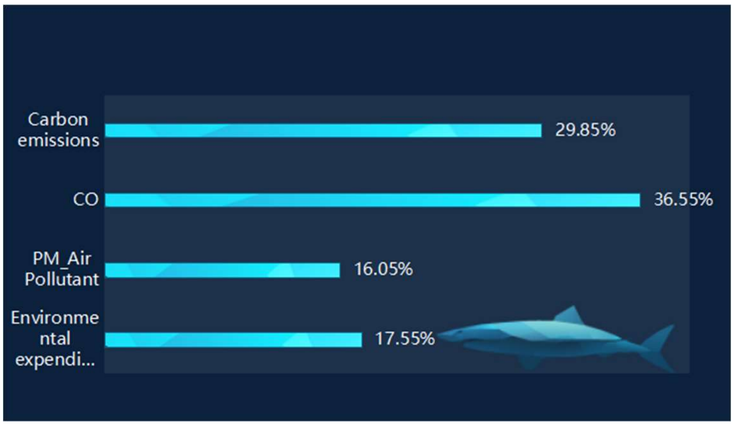

Figure 3. Summary of weight calculation results by entropy method

Set $E = -b_1CO_2 - b_2CO - b_3CH^4 + b_4C$,So $E = -0.2985CO_2 - 0.3655CO - 0.1605CH^4 + 0.1755C$ We used the 2013-2023 Mean_Concentration_of_Diesel_PM_Air_Pollutant, Gross total, Annual_Emissions_Nitrous_Oxide_NonBiogenic, and Government spending on environmental protection data to obtain E for 2013-2023 and predicted a value of 0.363 for E in 2024 using ARIMA. Based on the Passenger volume data from 2012-2022, we calculated the normalized mean value of P as 0.366607246, P^2=0.13439556, and set b_5=1, we calculated the ecological environment index E_{nv} from 2014-2024, and performed descriptive analysis on it, which resulted in the ecological environment index E_{nv} with a The mean value is 0.401 and the standard deviation σ is 0.102. According to the 3σ principle, Set $E_{nv_{min}} = \mu - k\sigma$

(5) For the survival quality index SQ. Set $SQ = c_1I - c_2L - c_3N - c_4lnp$,

where I denotes the average income growth rate, L denotes the population unemployment rate, and N denotes the number of occupants.

Using the entropy weighting method with the data of number of occupants, population unemployment rate, and average income growth after normalization from 2013 to 2022 c_1=0.2743, c_2=0.3067, c_3=0.419

Considering all the external factors, take the value of k as 2, i.e., $E_{nv} \geq E_{nv_{min}} = 0.197$

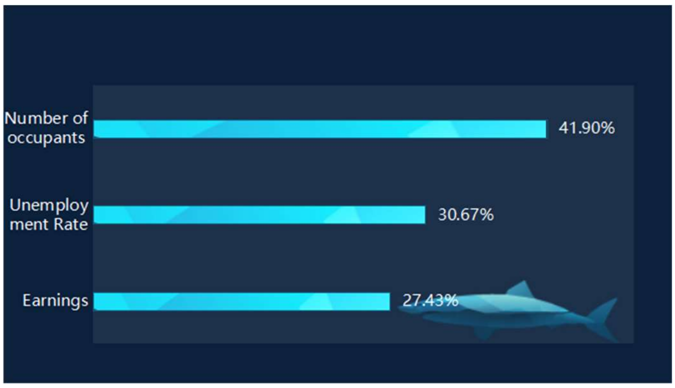

Figure 4. Summary of weight calculation results by entropy method

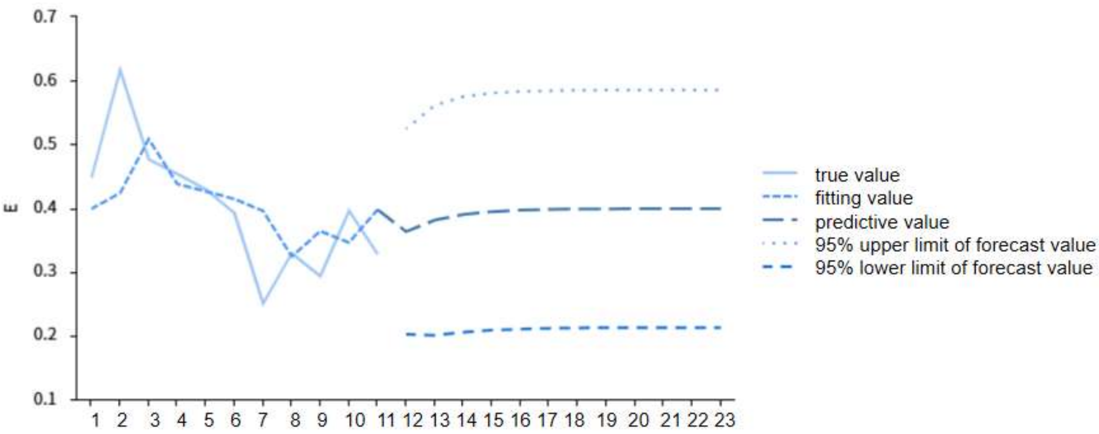

Figure 5. E Model Fitting Prediction

Set $SQ_1 = c_1I - c_2L - c_3N$, so $SQ_1 = 0.2743I - 0.3067L - 0.419N$. The same method of calculating the data for 2013-2023E was used to obtain the data for SQ_1 for 2013-2023,and ARIMA was used to predict the value of SQ_1 for 2024 as 0.478, with a P-normalized mean value of 0.366607246, so lnp=-0.43579895544931657, set c_4=1. We calculated the survival quality index SQ for 2014-2024 and analyzed it descriptively, yielding a mean of 0.512 and a standard deviation σ of 0.191 for the survival quality index SQ. According to the 3σ principle, set SQ_{min}=$\mu - k\sigma$. Taking the value of k to be 1, considering various external factors, so $SQ \geq SQ_{min} = 0.321$.

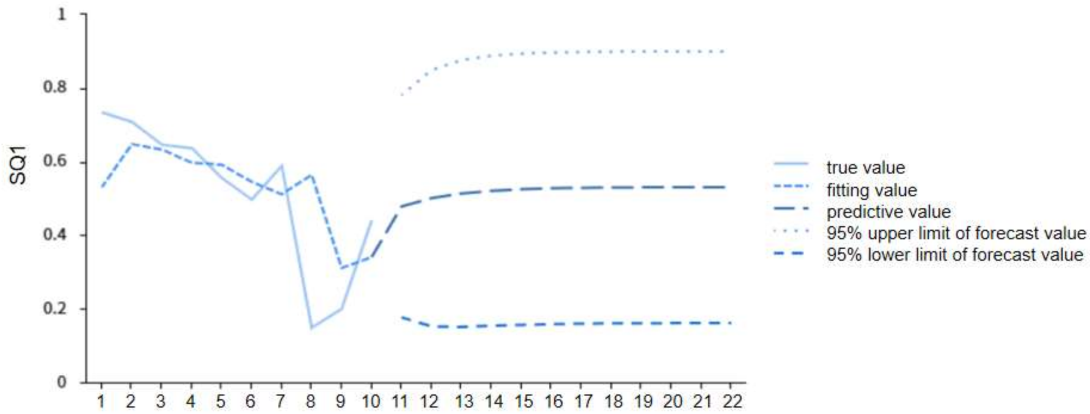

Figure 6. SQ_1 Model Fitting Prediction

(6) For the number of tourists P, we use the data of the last ten years to calculate the mean value of P as 1087100 and the standard deviation as 100682.615. According to the 3σ principle, set $P_{max} = \mu + k\sigma$.Taking the value of k to be 1, considering various external factors, so

$$P \leq P_{max} = 1187782$$

5.3.2. Genetic Algorithm

(1) Basic principle: Genetic Algorithm (GA) is one of the first population-based stochastic algorithm proposed in the history[3]. GA is an optimization algorithm that draws on Darwin's theory of natural selection and Mendel's principles of genetics, and its core idea is to search for the optimal solution by simulating the biological evolutionary process.

(2) Steps

ISSN: 2710-0723

Step 1: Initialization. Set the number of iterations M and the maximum number of generations G. Generate N random site coordinates as the initial population.
Step 2: Initial evaluation. Calculate the sum of distances from each coordinate to the target cell as the fitness.
Step 3: Selection operation. According to the number of service cells, divide the population into good and bad individuals.
Step 4: Crossover operation. Cross the inferior individuals with the superior individuals in order to approach the superior individuals.
Step 5: Variation operation. Perform high probability mutation on poor individuals and low probability mutation on good individuals to prevent local optimization.
Step 6: Cyclic operation. Generate a new generation of population through selection, crossover and mutation, calculate the fitness and compare with the previous generation to select the better result.
Step 7: Termination condition. If the number of iterations or the fitness target is reached, then terminate; otherwise, return to Step 3 and continue.

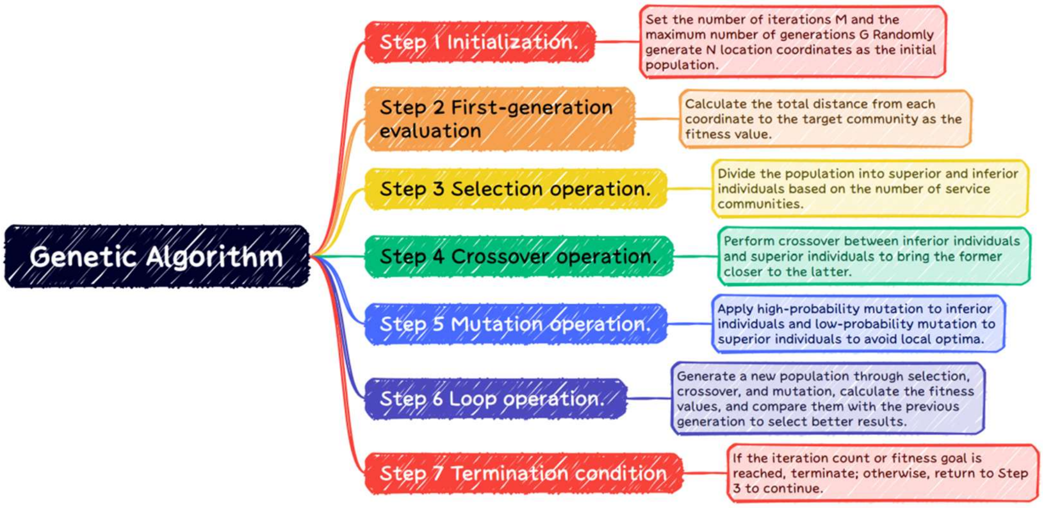

Figure 7. Genetic algorithm flow chart

(3) Optimal solutions and optimal values

Table 4. Genetic algorithm results

Parameter	Value
u	10.886977
Y	166321.324
C	143462.94
S	153036.342
P	97.378

5.3.3. Sensitivity Analysis

(1) Purpose: In order to assess the impact of the key parameter per capita tourism consumption expenditure (y) on our model and the robustness of the model.

ISSN: 2710-0723

(2) Method: Change the value of y (1708) in steps of 10 and repeat 20 times to get the value interval of y as [1608,1798], keep the other parameters total income (Y), environmental protection cost (C), social cost (S) and the number of tourists (P) unchanged, and observe the change of the model output (u)

(3) Sensitivity analysis results:

Table 5. Sensitivity analysis results

average tourism consumption per person	Y	C	S	P	u
1608	115416.049	101838.363	109354.905	71.776	10.886977
1618	120278.653	105884.986	113615.07	74.338	11.325957
1628	125223.291	109988.101	117931.565	76.918	11.771432
1638	130476.05	114369.388	122537.274	79.656	12.246090
1648	135140.301	118149.836	126508.578	82.003	12.659957
1658	140293.598	122385.806	130955.392	84.616	13.121160
1668	145316.242	126469.723	135239.626	87.12	13.567520
1678	150508.226	130695.784	139669.977	89.695	14.029133
1688	155722.757	134920.018	144095.421	92.253	14.491273
1698	160995.525	139177.44	148552.662	94.815	14.957521
1708	166321.324	143462.94	153036.342	97.378	15.427354
1718	171756.016	147831.393	157603.814	99.974	15.906374
1728	177144.851	152130.797	162096.191	102.514	16.379061
1738	182233.585	156111.316	166252.85	104.852	16.819925
1748	188212.624	160942.583	171294.704	107.673	17.348330
1758	193697.423	165264.135	175801.71	110.181	17.825442
1768	199351.206	169727.767	180454.052	112.755	18.317768
1778	205005.715	174168.038	185079.231	115.301	18.808433
1788	210788.244	178710.166	189807.659	117.891	19.310202
1798	216500.012	183158.563	194435.763	120.412	19.803145

To visualize the results, we plotted the sensitivity analysis as follows:

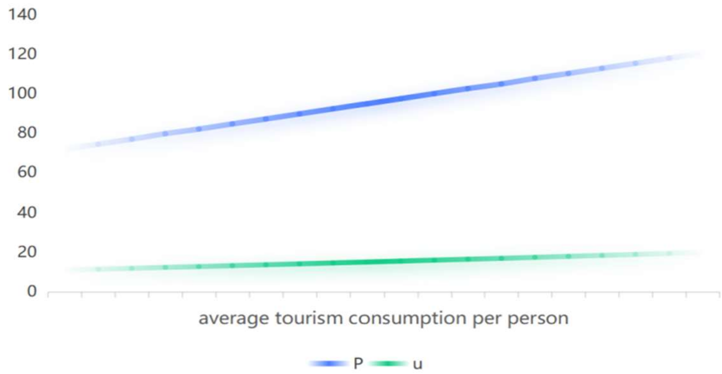

Figure 8. u and P sensitivity analysis results are visualized

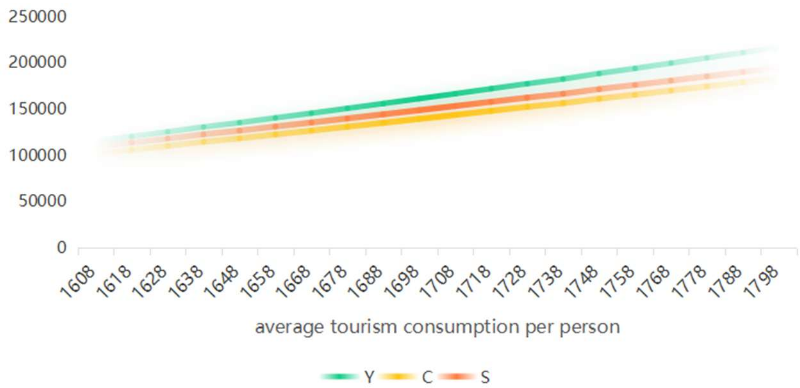

Figure 9. Visualization of YCS sensitivity analysis results

(4) Analysis of sensitivity analysis results:

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Influence of y on u: The value of u shows an increasing trend with the increase of y. The value of u shows an increasing trend with the increase of y. Within the interval [1608, 1798] of y, the change of u is small, which indicates that the influence of y on u is relatively limited.

Robustness of the model: Within the range of y, the change of u is relatively smooth, which indicates that the model is robust to the change of y. If the range of y is further expanded, the model is robust to the change of y. The model is robust to the change of y. If the range of variation of y is further expanded, the stability of the model may need to be reassessed.

5.3.4. Most Important Factors

Through the hierarchical analysis method, we compared the median personal income growth, hotel tax revenue, passenger volume, traffic volume, the average concentration of diesel particulate air pollutants, nitrous oxide concentration, carbon emissions, unemployment rate, the standard deviation of the glacier area of the data and assigning weights to them (Figure 9), and the results of the analysis show that the CI = 0.145,RI = 1.520,CR = 0.096 < 0.1 The result of consistency test passes, and the results of weight calculation are consistent.

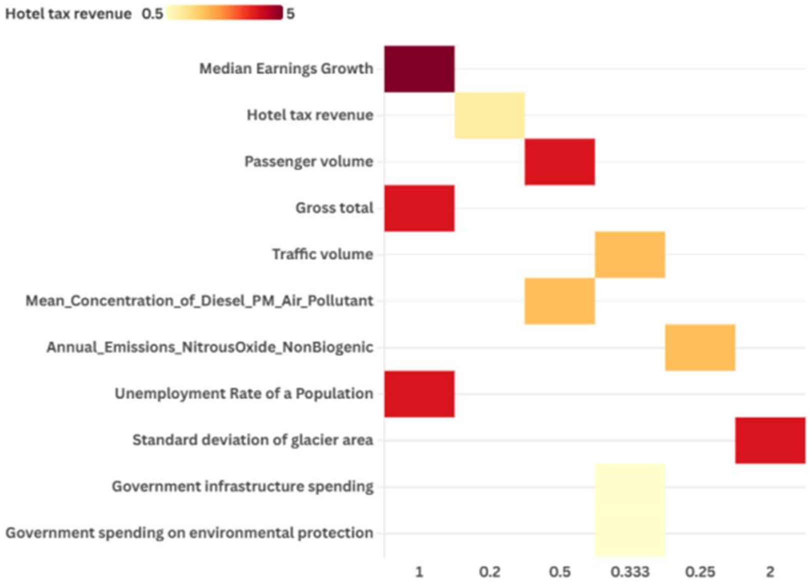

Figure 10. AHP judgment matrix

Figure 11. AHP analytic hierarchy process results

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Standard deviation of glacier area (18.85%) has the highest weight, indicating that glacier variability and uncertainty have a significant impact on decision making.Gross trail (18.39%) has the second highest weight, i.e., among all the criterion level factors, gross trail has a significant impact on the final decision (total return), and is used at the the later stage as a factor to focus on. Median Earnings Growth (13.13%) and Unemployment Rate (14.88%) have weights close to the median earnings growth, i.e., they have a certain impact on decision making, but are not decisive factors. While Annual_Emissions_NitrousOxide_NonBiogenic (5.28%), Mean_Concentration_of_Diesel_PM_Air_Pollutant (5.56%), Government infrastructure spending (5.95%), Traffic_volume (3.40%), Hospital revenue (4.07%), and Passenger volume (4.44%) are low weighted factors that can be considered as secondary in the decision making process.

5.4. Problem 2: Application of the Model to Other Attractions

5.4.1. Geographic Location of Fenghuang Ancient City and the Current Situation of Tourism Industry

Fenghuang Ancient City is located in the southwest of Xiangxi, Hunan Province, a city with a long history and unique culture. Located in the southwest of Xiangxi Tujia and Miao Autonomous Prefecture in Hunan Province, Fenghuang Ancient Town has a unique geographic location, with a backdrop of green mountains, facing the Tuojiang River, a beautiful shape and a unique natural environment. This unique geographical environment adds endless charm to Fenghuang Ancient Town, making it a tourist attraction in the hearts of many visitors. The geographic location of Fenghuang Ancient Town makes it a transportation hub at the junction of Hunan, Guizhou and Chongqing, providing convenient transportation conditions for the development of tourism. In addition, Fenghuang Ancient City is located at the edge of Hunan Province, close to Zhangjiajie, Changsha and other popular tourist cities, the transportation is convenient, which is conducive to attracting tourists and expanding the city's infrastructure imperfections, such as traffic congestion in the peak season, poor environmental health, insufficient number of public toilets, poor hygiene, and untimely cleaning of garbage, which affect the tourists' experience of visiting the city.

5.4.2. Model Adjustment and Application

For Phoenix Ancient City, we collected relevant data for its data processing, the data are as follows, and the model was adjusted accordingly, adjusting the average consumption expenditure of tourists y to 1000.4. By constantly adjusting the strategy variables and optimizing again with genetic algorithm to find the optimal strategy for sustainable development, the optimal value is 596.15.

Table 6. Phoenix Ancient City data

year	Number of Visitors Received (10,000 person-times)	tourism income	government investment in infrastructure construction	government spending on environmental conservation	carbon emissions	resident population	unemployment rate
2014	903.61	80.98	131.4	32.85	2799.171	357500	4.47
2015	1077.59	90.98	170.5	42.625	2933	345700	4.42
2016	1250	115	161.4	40.35	2903.143	327500	4.32
2017	1510	141	191.2	47.8	2918.243	329900	4.49
2018	1800.12	170.22	174.4	43.6	2961.286	339700	3.72
2019	2010.93	200.01	127.5	31.875	3132.814	349300	2.95
2020	1776.21	173.25	136.5	34.125	3004	352100	2.84
2021	2006.09	187.63	138.0	34.5	3166.371	353612	2.52
2022	2001.03	178.4	161.5	40.375	3059.4	351664	2.78
2023	1831.01	172.61	128.6	32.15	3009.86	341000	2.82

Considering the model results and the unique geographic location of Fenghuang Ancient City, the local government should take measures such as appropriately raising taxes, limiting the number of tourists, strengthening management and regulatory measures, and enhancing the treatment of wastewater and garbage, so as to promote the sustainable development of Fenghuang Ancient City.

5.4.3. Promotion of Cold Cities

(1) Tourism Development in Zhangye City

Zhangye City is located in the southwestern part of Gansu Province, China, with a long history, is an important city on the ancient Silk Road, and has unique natural scenery, known as “South of the River on the Seas”. The Zhangye Danxia National Address Park has helped revitalize this cold city. According to the Zhangye Culture and Tourism Bureau, the Zhangye Danxia National Geopark received about 3 million visitors in 2019, contributing 30% of Zhangye's tourism revenue[4]. The unique landscape of Danxia landform contributes to Zhangye not only in terms of tourism, but also in terms of politics, economy. For politics, with the development of tourism, Zhangye receives more policy support and financial investment for building infrastructure and environmental protection. For economy, Danxia Park drives the development of tourism in Zhangye, and the increase of tourists directly contributes to the prosperity of hotels, restaurants, transportation and other related industries.

(2) Related Suggestions

1) Dynamically adjust the number of tourists

Firstly, adjust the number of tourists appropriately during peak seasons[5] (e.g. Chinese New Year, summer vacation) and reduce the number of tourists during low seasons to achieve balance throughout the year. Secondly allocate tourist numbers to different time slots to avoid overcrowding during peak periods which may result in lower satisfaction of local residents

2) Optimize resource allocation

Firstly, dynamically adjust the use of infrastructure according to the number of tourists, e.g. close some facilities when there are fewer tourists to save resources.Then, enhance environmental protection measures when there are fewer tourists, such as vegetation restoration and garbage disposal.

3) Enhance visitor experience

Firstly, provide personalized tourism services, such as customized tourism routes and special catering, to attract more tourists. Also, increase cultural experience programs, such as handicraft production and folklore performances, to enhance tourists' participation and satisfaction.

(3) Model Extension to Zhangye Danxia Geopark

In order to maximize the total utility (sustainable development) and at the same time promote the development of local tourism, we improved the model.

1) Objective function

Objective function:

$$\max \mathrm{u} = \mathrm{A}_1 \mathrm{Y}^{\alpha} \mathrm{A}_2 \mathrm{S}^{-\beta} \mathrm{A}_3 \mathrm{C}^{-\gamma}$$

Among these, α=0.1638, β=0.539, γ=0.2973.

2) Adjustment constraints

A. Ecological environment index E_{nv}:

For attractions with fewer tourists and relatively less ecological pressure, the lower limit of E_{nv} can be appropriately relaxed. According to the 3σ principle, set $E_{nv_{min}} = \mu - k\sigma$. Considering all kinds of external factors, in order to make the conclusion more scientific, take the value of k 3, i.e. $E_{nv} \geq E_{nv_{min}} = 0.095$.

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Survival Quality Index SQ:

Since there are fewer tourists and the quality of life of residents is relatively less affected by tourists, the lower limit of SQ can be appropriately relaxed. According to the 3σ principle, set $SQ_{min}=\mu - k\sigma$. Considering all the external factors, in order to make the conclusion more scientific, take the value of k 2, i.e. $SQ \geq SQ_{min} = 0.13$.

Number of tourists P:

As the number of visitors to this attraction is relatively low, the upper limit

of the number of visitors can be appropriately adjusted upwards to attract more visitors and bring greater benefits. Set $P_{max} = \mu + k\sigma$,considering all the external factors, to make the conclusion more scientific, the value of k is taken as 2, i.e.

$$\mathrm{P} \leq P_{max} = 1288464$$

5.5. Model Advantages and Disadvantages

5.5.1. Advantages

This paper uses hierarchical analysis to decompose the complex sustainable tourism problem into multiple levels (e.g., economic, environmental, social), and systematically assesses the relative importance of each factor, and uses entropy method to determine the weights through the degree of discrete data to avoid the interference of subjective judgments, and finally genetic algorithm is used to optimize the number of tourists and resource allocation, which is suitable for use in complex optimization problems, and is robust. This model has a comprehensive, taking into account the influence of multiple factors, the model solution is scientific and objective, and can adjust the weights and constraints according to the different situations in different regions, which is flexible and has the ability to predict and optimize.

5.5.2. Disadvantages

Our model has high requirements for data, and needs to find a large amount of data before integration. In addition to this, the model has high computational complexity and involves a variety of complex mathematical methods and algorithms, requiring high computational resources and specialized skills.

ISSN: 2710-0723

5.6. Memorandum

TO: Juneau Tourism Commission

SUBJECT: Analysis and Recommendations for Sustainable Tourism Development in the City of Juneau

Glacier

1.Analysis of the Current Situation

(1) Rapid Tourist Growth: The number of cruise tourists in Juneau is rapidly increasing, which promotes economic growth but brings environmental pressure and leads to the degradation of the Mendenhall Glacier.

(2) Deterioration of Residents' Quality of Life: Insufficient waste disposal capacity, noisy living environment, and inadequate infrastructure are affecting residents' quality of life.

(3) Potential for Optimization Measures: Juneau can improve its environmental quality by implementing policies such as controlling the number of tourists.

2.Conclusion

(1) Controlling the Number of Tourists: According to our model, Juneau City should control the number of tourists within 1,187,782. This can effectively relieve the pressure on the environment, protect resources such as glaciers and forests, and at the same time, relieve the pressure on the infrastructure to provide better living conditions for residents.

(2) Eco-Environmental Index: A composite index obtained by weighted average of several related indexes, used to evaluate the ecological quality of the region. The higher the value, the better the environmental quality. In our model, we predict that the ecological environment index of Juneau City in 2024 will be 0.306, indicating relatively good environmental quality but still needing attention to environmental pressure.

(3) Quality of Life Index: A composite index obtained by weighted average of several related indices, used to evaluate the quality of the living environment in the region. Higher values indicate better quality of life. In our model, we predict that the Quality-of-Life Index for Juneau City in 2024 will be 0.478, suggesting improved quality of life but still needing attention to the impacts of the increase in the number of tourists.

3. Recommendations for optimizing the results

Recommendations Based on Model Analysis

(1) Dynamic Adjustment of Tourist Limits and Fees: Adjust the number of tourists and fees like hotel tax based on Juneau's tourism seasons to balance environmental protection and revenue.

(2) Infrastructure Improvement: Enhance Juneau residents' living environment by improving waste disposal and securing basic amenities like water supply.

(3) Promotion of Secondary Attractions: Increase publicity for secondary attractions like rainforests and whale watching to divert some tourists and reduce pressure on main glacier attractions.

4.Summary

Our model offers a precise, comprehensive solution for Juneau's sustainable development. By limiting tourists and dynamically adjusting policies, it protects the local ecosystem, secures residents' income, and enhances their life satisfaction. We hope the Juneau City Tourism Commission will adopt and implement our proposal, which can also serve as a reference for other tourist cities.

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Appendix

AHP hierarchical analysis (codes in Figures V and VI)

```
import pandas as pd
import numpy as np
df = pd.read_excel('Juneau data.xlsx')
# Guideline layer factors
criteria = [
    'Median Earnings Growth', 'Hotel tax revenue', 'Passenger volume', 'Gross total', 'Traffic volume',
    'Mean_Concentration_of_Diesel_PM_Air_Pollutant', 'Annual_Emissions_NitrousOxide_NonBiogenic',
    'Unemployment Rate of a Population', 'Standard deviation of glacier area',
    'Government infrastructure spending','Government spending on environmental protection',
]

n = len(criteria)
comparison_matrix = np.array([
    [1.000, 0.200, 0.500, 1.000, 0.333, 0.500, 0.250, 1.000, 2.000, 0.333, 0.333],
    [5.000, 1.000, 4.000, 4.000, 2.000, 2.000, 2.000, 4.000, 4.000, 0.500, 0.500],
    [2.000, 0.250, 1.000, 3.000, 1.000, 3.000, 3.000, 4.000, 5.000, 2.000, 2.000],
    [1.000, 0.250, 0.333, 1.000, 0.250, 0.333, 0.333, 0.500, 0.500, 0.250, 0.200],
    [3.000, 0.500, 1.000, 4.000, 1.000, 3.000, 3.000, 5.000, 5.000, 2.000, 2.000],
    [2.000, 0.500, 0.333, 3.000, 0.333, 1.000, 1.000, 4.000, 5.000, 2.500, 2.500],
    [4.000, 0.500, 0.333, 3.000, 0.333, 1.000, 1.000, 4.000, 4.000, 3.000, 3.000],
    [1.000, 0.250, 0.250, 2.000, 0.200, 0.250, 0.250, 1.000, 2.000, 0.250, 0.250],
    [0.500, 0.250, 0.200, 2.000, 0.200, 0.200, 0.250, 0.500, 1.000, 0.250, 0.250],
    [3.000, 2.000, 0.500, 4.000, 0.500, 0.400, 0.333, 4.000, 4.000, 1.000, 1.000],
    [3.000, 2.000, 0.500, 5.000, 0.500, 0.400, 0.333, 4.000, 4.000, 1.000, 1.000]
])
# Calculate eigenvalues and eigenvectors
eigenvalues, eigenvectors = np.linalg.eig(comparison_matrix)
max_eigenvalue = np.max(np.real(eigenvalues))
CI = (max_eigenvalue - n) / (n - 1)
print(CI)
print(max_eigenvalue)
# Selection of appropriate RI values based on the number of guidelines n
RI_value = 1.520  # RI value when n=11

# Calculate CR
CR = CI / RI_value
if CR < 0.1:
    weights = np.real(eigenvectors[:, np.argmax(eigenvalues)]) / np.sum(np.real(eigenvectors[:, np.argmax(eigenvalues)]))
```

ISSN: 2710-0723

```
    print("Criterion weights:", weights)
else:
    raise Exception("Unacceptable consistency of judgment matrices")
```

(α β γ AHP hierarchical analysis)

```
import pandas as pd
import numpy as np

df = pd.read_excel('Alpha AHP hierarchical analysis.xlsx')

# Guideline layer factors
criteria = ['Gross total','Government infrastructure expenditure','Government spending on environmental protection']

n = len(criteria)
comparison_matrix = np.array([
    [1.000, 0.333, 0.500],
    [3.000, 1.000, 2.000],
    [2.000, 0.500, 1.000]
]),
# Calculate eigenvalues and eigenvectors
eigenvalues, eigenvectors = np.linalg.eig(comparison_matrix)
max_eigenvalue = np.max(np.real(eigenvalues))
CI = (max_eigenvalue - n) / (n - 1)
print(CI)
print(max_eigenvalue)
# Selection of appropriate RI values based on the number of guidelines n
RI_value = 0.52 # RI value when n=3

# Calculate CR
CR = CI / RI_value
if CR < 0.1:
    weights = np.real(eigenvectors[:, np.argmax(eigenvalues)]) / np.sum(np.real(eigenvectors[:, np.argmax(eigenvalues)]))
    print("Criterion weights： ", weights)
else:
    raise Exception("Unacceptable consistency of judgment matrices")
```

(Data normalization code)

```
import pandas as pd
from sklearn.preprocessing import MinMaxScaler
import numpy as np
# Read Excel file with engine xlrd
df = pd.read_excel('Juneau.xls', engine='xlrd')
```

ISSN: 2710-0723

```
    # Negative sign in data, replace Unicode negative sign with ASCII negative sign
    df = df.replace('−', '-', regex=True)

    # Initialize the MinMaxScaler object
    scaler = MinMaxScaler()

    # Select all numeric columns for normalization
    numerical_columns = df.select_dtypes(include=[np.number]).columns
    df[numerical_columns] = scaler.fit_transform(df[numerical_columns])

    # Normalized data saved to Excel file, specify engine as openpyxl
    df.to_excel('normalize.xlsx', index=False, engine='openpyxl')

print("Normalization is complete, data has been saved to 'normalize.xlsx'")
```