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Original Article

Optimization of Sustainable Tourism Systems: A Fuzzy Comprehensive Evaluation Framework

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Abstract:
Juneau, Alaska, with a population of about 30,000, faced significant tourism pressure in 2023, hosting 1.6 million cruise passengers. While tourism brings substantial revenue, it also causes overcrowding and environmental damage, especially to the receding Mendenhall Glacier. This paper focuses on optimizing sustainable tourism in Juneau, using Fuzzy Comprehensive Evaluation (FCE), Entropy Weight Method (EWM), and Grey Relational Analysis (GRA) to address these challenges. The ARIMA model is applied to forecast future tourism trends, and the model is tested in Barcelona with sensitivity analysis to assess its adaptability and scalability.

First of all, the **Fuzzy Comprehensive Evaluation (FCE)** method is used to address the multi-level decision-making challenges in sustainable tourism development. By setting evaluation criteria and conducting data analysis, we comprehensively consider various influencing factors to derive accurate sustainability assessment results. Next, the **Entropy Weight Method (EWM)** is applied to automatically calculate the weights of each indicator based on their information contribution. This allows us to accurately reflect the importance of key factors in the sustainable tourism model and focus on the most influential indicators. Then, through **Grey Relational Analysis (GRA)**, the relationships between different factors are identified, helping us uncover the critical drivers of sustainable tourism development and their interactions. Finally, the **ARIMA model** is used to forecast data for the next five years, providing valuable insights into future tourism trends and informing long-term planning.

Based on the model developed in Task 1, we apply the same methods, including FCE, EWM, GRA, and ARIMA, to evaluate and optimize the sustainable tourism development of Barcelona, Spain. The model is adapted to account for the unique characteristics of Barcelona's tourism system. The results are then compared with those from Juneau to assess how the model can be effectively applied in different tourism contexts.

In order to evaluate the stability and scalability of the model, we perform a **sensitivity analysis**. The analysis explores whether the model can be adapted to larger or smaller tourism systems and assesses its applicability in other regions. By testing the model with varying parameters and scenarios, we investigate its robustness and capacity to handle diverse tourism systems, ensuring that the model is flexible enough to accommodate different regions and varying levels of tourism intensity.

Keywords: Sustainable Tourism; FCE; EWM; GRA; ARIMA Model.

1 Introduction

1.1 Problem Background

With the continuous increase in tourist numbers, Juneau faces the challenge of balancing the protection of its natural environment with the need to maintain economic prosperity. In recent years, the hidden costs of tourism have emerged as a significant issue for many tourist destinations worldwide. Particularly in environmentally sensitive areas, the pressure exerted by tourist activities not only manifests in the consumption of local infrastructure, such as water supply and waste management, but also in the increased carbon footprint. Additionally, local residents are facing social issues such as housing shortages, rising property prices, and overcrowding.

In response to these challenges, Juneau has implemented a series of measures, including raising hotel taxes, increasing visitor fees, limiting the number of daily visitors, and imposing stricter regulations on alcohol sales. The additional revenue generated from these taxes and fees is being used to support ecological conservation, improve infrastructure, and promote community development projects. However, many residents who depend on tourism for their livelihood are concerned that the rising costs may drive tourists away and prefer a continued increase in visitor numbers to boost business growth. On the other hand, a significant number of locals have expressed dissatisfaction with the negative impact of overtourism and some have even chosen to leave or publicly protest.

Therefore, finding a balance between the economic benefits derived from tourism and the environmental pressures it creates, as well as developing tourism in a sustainable manner, has become a critical issue that Juneau urgently needs to address. In the future, the formulation of reasonable management policies and the promotion of sustainable tourism development will not only directly impact the economic stability of Juneau but also have profound implications for its social and environmental well-being.

1.2 Restatement of the Problem

To achieve sustainable tourism development in Juneau, Alaska, we need to establish a model to optimize the operation of the tourism system, ensuring that economic prosperity is maintained while effectively protecting the natural environment. This model will analyze and adjust the development trajectory of tourism from multiple perspectives and levels, and ensure that, once optimized, it can have a positive impact on global economy, environment, and health.

The specific tasks to be completed include:

- Optimization of the existing tourism system model:

- Optimization factors: The primary optimization goal is to ensure the tourism industry thrives without damaging the natural environment. Specific factors to optimize include the number of visitors, tourism revenue, and environmental protection measures.

- Constraint factors: The limiting factors include environmental capacity, infrastructure carrying capacity (such as water resources, waste management), and the social tolerance of local residents.

- Sensitivity analysis: Conduct a sensitivity analysis of various factors within the model, discussing which elements are most critical to the sustainability of tourism, such as the number of visitors, revenue, and environmental impact.

- Discussion of model scalability:

- Discuss how this model can be applied to other tourist destinations impacted by overtourism, analyzing the needs and prioritized measures for different regions.

- Explore how promoting lesser-visited attractions or areas can lead to a better distribution of tourists, alleviating the pressure on certain tourist hotpots.

- Recommendations to the Juneau Tourist Council: Prepare a concise report outlining predictions, the effects of various measures, and suggestions for optimizing the tourism industry.

Through these steps, we aim to develop a sustainable tourism strategy for Juneau that balances economic growth with environmental protection and fosters comprehensive development of the local community.

1.3 Our Work

In this paper, we aim to optimize the sustainable tourism development model for Juneau, Alaska. We first apply the fuzzy comprehensive evaluation method[1] to address the multi-level decision-making problems in sustainable tourism development. By setting evaluation standards and performing data analysis, we comprehensively consider the influence of various factors and obtain an accurate sustainability assessment. Next, we use the entropy weight method[2], which automatically calculates the weights of each evaluation indicator based on their informational contribution, allowing us to accurately reflect the importance of each factor in the sustainable tourism model and focus on the most influential indicators. Through grey relational analysis, we identify the relationships between various factors and uncover the key factors and their interactions that impact sustainable tourism development. Finally, we conduct a sensitivity analysis to examine the model's stability and scalability, analyzing its applicability to larger or smaller tourism systems and assessing its adaptability to other regions. Through these analyses, we aim to develop a reasonable sustainable tourism development strategy for Juneau and provide insights for other regions impacted by overtourism.

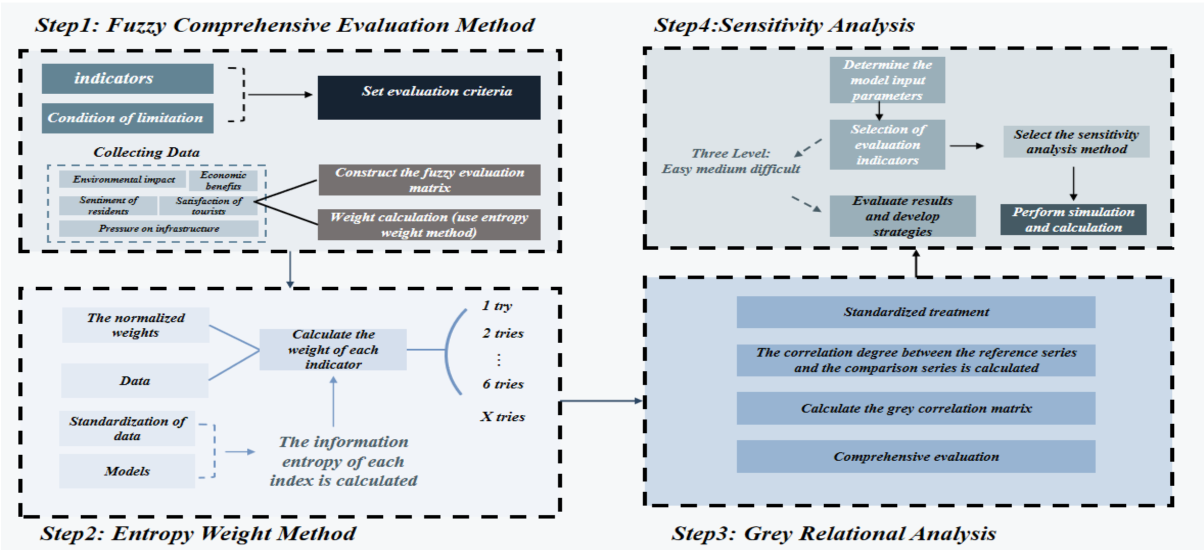


Figure 1 Flow Chart

2. Assumptions and Justifications

In this study, several assumptions were made to simplify the evaluation of sustainable tourism. The following are the primary assumptions along with their justifications:

▼**Assumption1:** Visitor Volume Fluctuation Assumption

▲**Explanation:** It is assumed that the number of visitors fluctuates according to seasonal changes and infrastructure limitations, with a maximum capacity established. This assumption is justified as tourist destinations have limited capacity, and both environmental and social carrying capacities impose constraints on visitor numbers.

▼**Assumption2:** Revenue Generation Assumption

▲**Explanation:** It is assumed that each visitor generates a fixed amount of revenue, primarily from accommodation, dining, and related services. This assumption is based on the general patterns of tourist spending behavior, which, while varying for individual visitors, tends to remain relatively stable overall.

▼**Assumption3:** Infrastructure and Environmental Protection Expenditure Assumption

▲**Explanation:** It is assumed that the revenue generated from tourism will be allocated towards infrastructure development and environmental protection. This assumption is grounded in the practice of many tourist destinations, which use taxes and fees collected from tourism to improve the tourism experience and preserve natural resources. For instance, whale-watching tourism requires improvements in port facilities, iceberg tourism necessitates stronger environmental protection measures, and rainforest tourism demands further investments in ecological conservation.

▼**Assumption4:** Environmental Impact Assumption

▲**Explanation:** It is assumed that the environmental impact of tourism is proportional to the number of visitors. A larger number of visitors typically results in higher environmental pressures, such as increased waste and resource consumption. This assumption is reasonable as the growth in visitor numbers often leads to a corresponding increase in environmental strain.

▼**Assumption5:** Local Resident Sentiment Assumption

▲**Explanation:** It is assumed that local residents' sentiment changes in response to variations in visitor numbers and quality of life. Resident sentiment significantly influences the social sustainability of tourism. If the influx of tourists leads to negative impacts, such as overcrowding or increased costs of living, resident support for tourism may decrease.

3. Symbol Explanation

For convenience, we use the following symbols in our models, as shown in the table below.

Table 1: Notations used in this paper

Symbol	Description
V	Total number of visitors
R	Total income generated from tourism activities
I	Investment in infrastructure and conservation efforts
L	Anti-Tourism Sentiment
E	Environmental impact
P	Pressure on infrastructure
G	Tourism growth rate
A	The attractiveness of alternative

4. Task1

4.1 Research method introduction and evaluation index system

This study, based on the theory of optimizing the tourism industry structure, systematically reviews the literature and integrates existing research findings to develop a sustainable tourism evaluation framework for Juneau, Alaska. The framework incorporates three dimensions of sustainability—economic, environmental, and social—as primary indicators. Through interviews and consultations with experts in tourism-related fields, the indicators were further refined according to principles of system optimization, hierarchy, scientific feasibility, comprehensiveness, representativeness, and dynamic stability. The final selection comprises 11 secondary indicators (Table2)

1) Economic Sustainability Dimension[3]: Four secondary indicators—tourism revenue, tourism taxes, tourism growth rate, and employment opportunities—were selected. These indicators reflect the direct contribution of tourism to the local economy, the fiscal contribution to government finances, the development trend of the tourism industry, and the role of tourism in promoting local employment.

2) Environmental Sustainability Dimension: The environmental impact indicator quantifies the effects of tourism on natural resources and ecosystems[4]. The infrastructure and environmental protection investment indicator reflects local investments in infrastructure construction and environmental protection, while the natural resource consumption indicator measures the dependence of tourism on and its consumption of natural resources.

3) Social Sustainability Dimension: The local sentiment indicator reflects the impact of tourism on local residents[5]. Positive sentiment supports tourism development, while negative sentiment may lead to social conflicts. The infrastructure pressure indicator assesses the burden that tourism places on local infrastructure. Tourist satisfaction affects revisit rates and recommendations, fostering the long-term development of tourism[6]. The cost-of-living indicator reflects the impact of tourism on the quality of life for local residents.

Table 2: Juneau tourism industry sustainability evaluation system

destination layer	Primary index layer	Secondary index layer	Local weight	Global weight
Tourism Industry Sustainability Evaluation (U)	Economic Sustainability	Total revenue	0.40	0.22
		Tourism tax/fee	0.20	0.11
		Tourism growth rate	0.15	0.08
		Job creation	0.25	0.14
	Environmental Sustainability	Environmental impact	0.35	0.12
		Investment in infrastructure and conservation	0.40	0.14
		Natural resource consumption	0.25	0.09
	Social Sustainability	Local sentiment	0.30	0.09
		Pressure on local infrastructure	0.20	0.06
		Tourist satisfaction	0.30	0.09
destination layer	**Primary index layer**	**Secondary index layer**	**Local weight**	**Global weight**

Based on the aforementioned indicators, we developed a comprehensive evaluation system for sustainable tourism development in Juneau. First, the Fuzzy Comprehensive Evaluation method was applied to perform fuzzy evaluation and normalization of the indicators, resulting in the construction of a fuzzy evaluation matrix. Next, the Entropy Weight Method was used to determine the weights of each secondary indicator, ensuring the objectivity and scientific rigor of the weighting process. The fuzzy evaluation matrix was then multiplied by the weight vector through matrix operations to obtain the comprehensive scores for each primary indicator. These scores were subsequently aggregated through weighted summation to derive the final overall sustainability assessment score. After determining the weights of the secondary indicators, Grey Relational Analysis was further used to assess the degree of impact of each primary indicator on overall sustainability. The indicators with the highest correlation were identified as having the greatest impact on overall sustainability, which formed the basis for developing strategies for optimizing the tourism industry structure in Juneau.

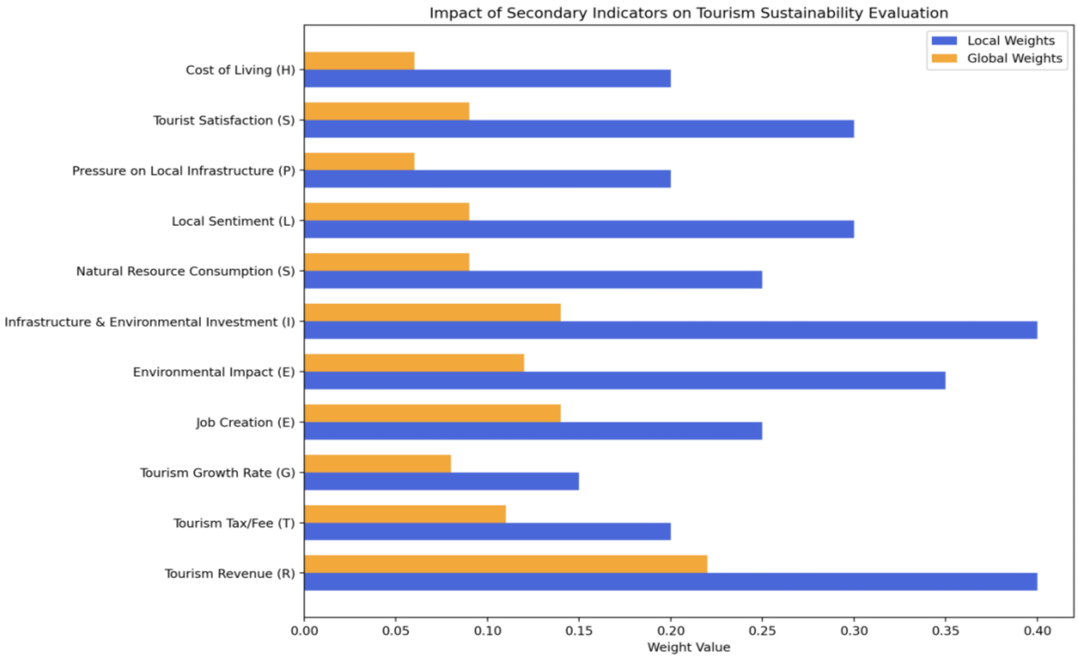


Figure 2 Impact of Secondary Indicators on Tourism Sustainability Evaluation

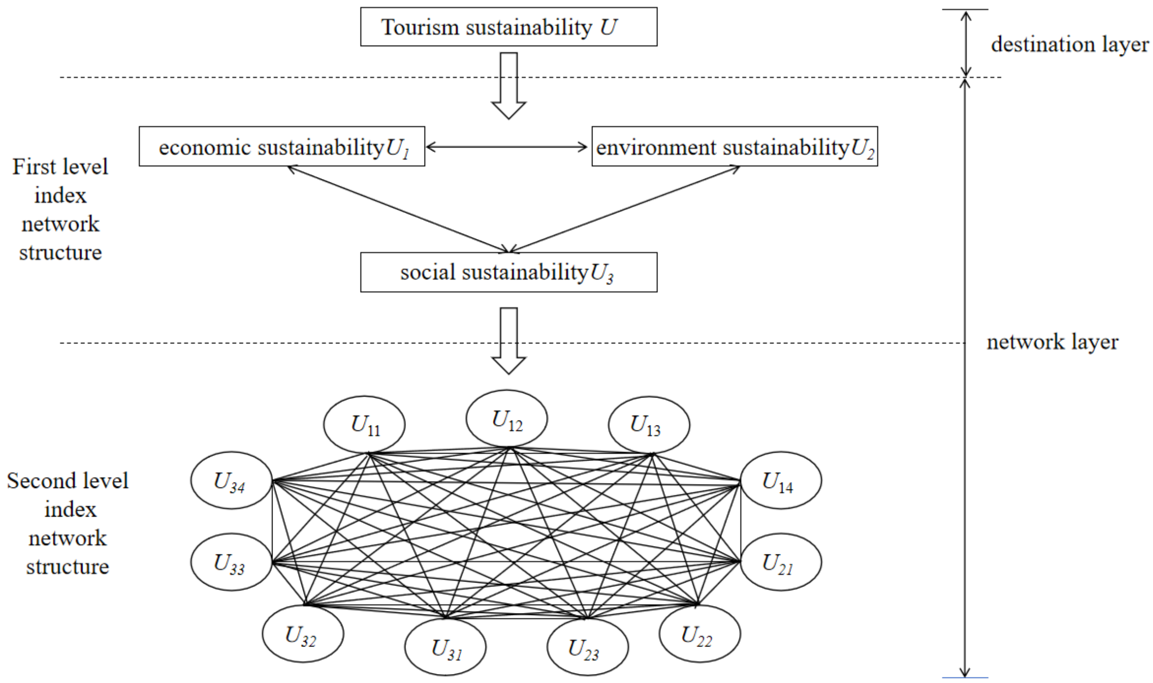
Tourism Revenue (R) has a local weight of 40% in economic sustainability but a global weight of

22%, showing its significant but relatively lower overall contribution. Job Creation (E) holds a local weight of 25% and a global weight of 14%, indicating its greater impact on economic sustainability than on the overall evaluation. For Environmental Sustainability, both Environmental Impact (E) and Infrastructure & Environmental Investment (I) have high local weights (0.35 and 0.40) and global weights (0.12 and 0.14), reflecting their importance. In Social Sustainability, Tourist Satisfaction (S) has a local weight of 0.30 and a global weight of 0.09, highlighting its significant contribution to the overall assessment.

4.2 Weight Determination and Grey Relational Degree Analysis

(1) Identification of the Impact Relationships Among Different Indicators in the Tourism Industry Sustainability Evaluation System. Experts in tourism-related fields were invited to assess the presence and strength of direct influence relationships among all indicators, resulting in the construction of a judgment matrix. After normalizing this matrix, a normalized matrix was obtained, followed by averaging each row to calculate the initial local weight for each secondary indicator. Once the initial local weights for all indicators were computed, they were further normalized so that their sum equaled 1, resulting in the final local weights. The global weight represents the contribution of each secondary indicator to the overall sustainability evaluation system, which was calculated through a weighted sum of the primary and secondary indicator weights[7].

(2) Construction of the Sustainable Tourism Evaluation System Network Based on the impact relationships among different indicators identified through Fuzzy Comprehensive Evaluation and the Analytic Hierarchy Process (AHP), a sustainable tourism evaluation system network is constructed for the optimization of the tourism industry structure. (Figure 3)



4.2.1.1.1.1 Network structure of tourism industry sustainability evaluation system

Calculation of the Comprehensive Evaluation Score Using the Entropy Weight Method. The weight vector for the three primary indicators is denoted as $W = [w_1, w_2, w_3]$, representing economic, environmental, and social sustainability, respectively. The final sustainability evaluation score, Y, is the weighted sum of the comprehensive evaluation results for all primary indicators[9]. This score provides a measure of the overall sustainability of the tourism industry. A higher score indicates that the tourism industry performs well in terms of economic, environmental, and social sustainability, while a lower score suggests significant pressure on the local environment, society, and economy, indicating the need for optimization of the tourism industry structure.

$$Y = w_1 \cdot Y_1 + w_2 \cdot Y_2 + w_3 \cdot Y_3 \quad (1.)$$

4) Grey Relational Analysis, a multivariate analysis method based on Grey System Theory, is used to explain the relationships between different factors. Through this analysis, we can gain a clearer understanding of how each factor (such as economic, environmental, and social sustainability indicators) impacts overall sustainability. First, the three sets of primary indicator scores—Y1, Y2, and Y3—obtained in Step 3, as well as the final comprehensive sustainability score Y, are standardized using the range method to eliminate dimensional differences between the indicators. The formula is as follows:

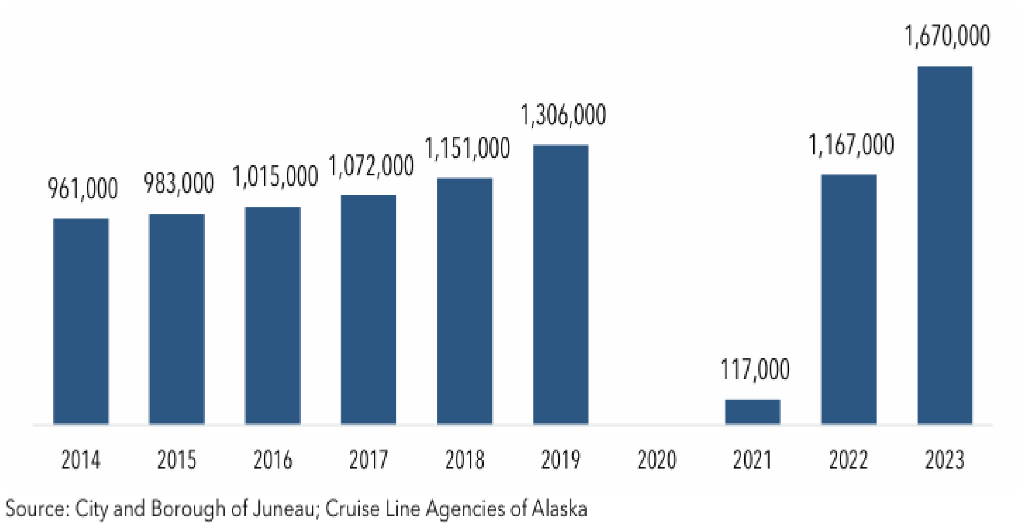
$$x'_{ij} = \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)} \quad (2.)$$

Select the overall sustainability score as the reference sequence, and the economic, environmental, and social sustainability scores as the comparison sequences. The grey relational degree between each pair of reference sequence and comparison sequence is calculated using the following formula：

$$\xi_{ij} = \frac{\min_{i,j} \Delta y_{ij} + \rho \cdot \max_{i,j} \Delta y_{ij}}{\Delta y_{ij} + \rho \cdot \max_{i,j} \Delta y_{ij}} \quad (3.)$$

Finally, the total grey relational degree for each comparison sequence is calculated using the following formula. The primary indicator with the highest grey relational degree to the overall sustainability score Y indicates that it has the greatest impact on overall sustainability. By comparing the grey relational degrees of each primary indicator, we can determine which aspect has the most decisive influence on the sustainability of the tourism industry.

$$\xi_k = \frac{1}{n} \sum_{i=1}^{n} \xi_{ik} \quad (4.)$$



4.2.1.1.1.2 Juneau Cruise Passenger Volume

Nearly 1.7 million cruise passengers visited Juneau between April and October 2023, up 74% (around 700,000 passengers) from a decade earlier, and up 28% from the previous peak in 2019. Approximately 36,000 crew members sailed to Juneau in 2023.

4.3 Time Series Prediction and Future Trend Analysis

To predict the sustainable development trends of Juneau's tourism industry for the next five years, this study combines the Grey Forecasting Model (GM (1,1)) and the ARIMA model for time series forecasting. ARIMA is a widely used statistical model for time series prediction, effectively capturing trends, seasonality, and random fluctuations in data, particularly suitable for modeling and forecasting stationary time series. The core idea of the ARIMA model is to model the time series using the autoregressive (AR) and moving average (MA) components while removing trends through a differencing (1) step. In this study, we selected ARIMA(1, 1, 1) as the initial model to fit the historical visitor data from Juneau (2019 to 2023) and used the model's parameters to forecast visitor numbers for the next five years (2024-2028).

Where:

- p = 1 indicates the use of one past observation to predict the current value;

- d = 1 means that the data is differenced once to remove trends;

- q = 1 means that one past error term is considered to optimize the forecast.

(1) Differencing (l = 1): The first-order differencing compares each value in the time series with its preceding value, removing trends and making non-stationary time series stationary. The differencing formula is as follows:

$$Y_t' = Y_t - Y_{t-1} \quad (5.)$$

(2) Auto-regressive (AR = 1): The auto-regressive model predicts the current value using past observations. In ARIMA (1, 1, 1), this means using the difference value from the previous time point to predict the current value. The auto-regressive formula (AR part) is as follows: （ϕ_1It's an auto-regressive coefficient, Y_t'Is the time series value after difference, Y_{t-1}'It's the difference from the previous moment, ϵ_tIs the white noise error term）

$$Y_t' = \phi_1 Y_{t-1}' + \epsilon_t \quad (6.)$$

(3）Moving average (MA = 1) : The activity average model corrects the current forecast through the past error term, it takes into account the error of the previous moment to adjust the predicted value of the current moment. The moving average formula is as follows (MA= 1)（θ_1Is the moving average coefficient, ϵ_tIs the current white noise error term, ϵ_{t-1}It's the error term from the previous moment）

$$Y_t' = \epsilon_t + \theta_1 \epsilon_{t-1} \quad (7.)$$

(4）Combined formula, combining AR and MA parts, ARIMA (1,1,1) model can be represented by the following formula. From this, we get a stationary sequence, through which ARIMA model makes autoregressive and moving average predictions.

$$Y_t' = \phi_1 Y_{t-1}' + \epsilon_t + \theta_1 \epsilon_{t-1} \quad (8.)$$

(5）According to the forecast results of the ARIMA model, the number of tourists in Juneau will show slight fluctuations in the next five years, and the specific forecast values are as follows:

These projections suggest that June visitor numbers will remain stable over the next five years, with an average annual number of visitors between 2.57 and 2.59 million. To be specific:

The number of tourists in 2024 is projected to be 2,573,297, the lowest of the projections and a slight decrease from 2023. This may reflect certain uncertain factors, such as fluctuations in the global economy or changes in tourist travel preferences.

The number of tourists projected for 2025 and 2026 is 2,594,630 and 2,588,587, respectively, indicating a small increase or fluctuation in the number of tourists. This growth is likely to be driven by factors such as the increased resilience of the tourism industry, increasing demand from tourists.

The number of tourists is projected to be 2,590,299 and 2,589,814 by 2027 and 2028, remaining close to the levels of 2025 and 2026, showing some stability.

These projections suggest that Juno's tourism industry is likely to continue its steady growth in the coming years, with visitor numbers staying close to 2.6 million. This provides valuable trend prediction for relevant tourism industry chains (such as retail, hotels, catering, tour guides, etc.) and local governments, which can provide reference for resource allocation and policy making.

4.4 Sensitivity Analysis

In this study, we evaluated the sensitivity of the Juneau sustainable tourism model to changes in key parameters through sensitivity analysis. Sensitivity analysis helps identify which factors have the greatest impact on the model results and helps us understand which factors may need to be focused on in actual decisions. Here are a few important parameters that change in different situations.

1. Changes in the Number of Tourists (V)

It is assumed that the number of visitors to Juneau will fluctuate, especially during the peak tourist season. We chose a hypothetical range of 10% increase or decrease from the current number of visitors (2,648,600). To simulate this change, we split visitor numbers into three scenarios:

Table 3: Changes in the number of tourists

V	**2648600**	**2913460**	**2384740**
Economic Sustainability Score (Y1)	0.80	0.85	0.75
Environmental Sustainability Score (Y2)	0.75	0.70	0.80
Social Sustainability Score (Y3)	0.78	0.76	0.79

2. Changes in Infrastructure Investment (I)

We also modelled the impact of changes in infrastructure investment on tourism sustainability assessments. Assuming a 5% increase or decrease in infrastructure investment, higher and lower levels of investment, respectively:

Table 4: Changes in infrastructure investment

I	**15000000**	**15750000**	**14250000**
Economic Sustainability Score (Y1)	0.80	0.82	0.78
Environmental Sustainability Score (Y2)	0.75	0.78	0.70
Social Sustainability Score (Y3)	0.78	0.79	0.76

3. **Changes in Tourist Satisfaction** (S)

Tourist satisfaction directly affects social sustainability indicators. Suppose satisfaction scores can vary by 5%:

Table 5: Changes in tourist satisfaction

tourist satisfaction (S)	85%	89%	81%

Economic Sustainability Score (Y1)	0.80	0.82	0.78
Environmental Sustainability Score (Y2)	0.75	0.76	0.73
Social Sustainability Score (Y3)	0.78	0.80	0.75

When tourist satisfaction increases, the social sustainability score increases, indicating that high tourist satisfaction is associated with social stability, resident support, and long-term sustainability of tourism. Conversely, when visitor satisfaction decreases, social sustainability scores also decline, affecting residents' mood and social stability.

Through sensitivity analysis, we found that the number of tourists has a significant impact on economic and environmental sustainability, and in particular, environmental sustainability decreases significantly when the number of tourists increases, so measures need to be taken to balance the number of tourists with environmental protection. Infrastructure investment has a positive impact on various sustainability indicators, suggesting that upgrading infrastructure can enhance the sustainability of tourism. Tourist satisfaction has a direct impact on social sustainability, and maintaining a high degree of satisfaction is conducive to long-term social stability and development.

5. Task2：Barcelona Model Application

5.1 Analysis of Tourism Industry Structure in Barcelona

Barcelona, a major tourist destination, welcomed about 30 million visitors in 2019. However, tourism sharply declined in 2020 due to COVID-19, with a gradual recovery in 2021 and 2022. In 2019, tourism revenue was about $10.8 billion, making up 14% of the city's GDP. Since 2012, a "tourist tax" has been implemented, ranging from 0.72 to 2.25 euros per night, depending on accommodation type.

While tourism boosts the economy, it also causes negative impacts, such as:

1. Environmental Issues: Tourism generates 1.1 million tons of carbon emissions annually, along with beach pollution and degradation of heritage sites like Gaudí's Sagrada Familia.

2. Economic Strain: Tourism contributes to traffic congestion (20-25% of city center traffic) and increases demand for water and waste management services.

3. Social Challenges: The rise of short-term rentals, like Airbnb, has driven up housing costs, and many residents are dissatisfied with over-tourism, with 50% reporting it negatively affects their daily lives.

5.2 The Tourism Sustainability Evaluation Model Was Introduced to Analyze the Tourism Industry Structure in Barcelona

Table 6: variable

Symbol	Description	Assumption	Source & Notes	Formula
V	Total number of visitors	The number of visitors to Barcelona in 2021 is 30 million	Tourism continued to recover in 2021.	/
R	Total income generated from tourism activities	2021: €4 billion	Recovery of tourism revenue as the industry rebounded in 2021.	$R = V * 300$
C	The cost of managing visitors	The management cost per visitor is €50	/	$C = V * 50$
I	Investment in infrastructure and conservation	The annual investment is 50 million euros	/	

	efforts			
S	Satisfaction of tourists	Tourist satisfaction is inversely related to the number of tourists and management costs	/	$S = 10 - (\frac{C}{V * 100})$
L	Anti-Tourism Sentiment	P and E are infrastructure pressure and environmental impact, respectively	Adjustment de Barcelona: Survey of residents' opinions on overtourism.	$L = 5 - \left(\frac{P}{V}\right) - \left(\frac{E}{V}\right)$
T	Taxes and fees levied by tourists	€2.25/ night (luxury accommodation)	Luxury hotel tax per person per night	T = V * 20
E	Environmental impact	1.1 million tons CO_2	Adjustment de Barcelona: Annual carbon emissions from tourism.	E = V * 0.5
P	Pressure on infrastructure	15%-20%	Contribution of tourism to public transport usage (subway, buses, etc.).	$\frac{V}{Infrastructure\ capacity}$
G	Tourism growth rate	Growth rate of 5%	/	G = 0.05 * V
A	The attractiveness of alternative destinations	The attractiveness of alternative destinations is correlated with tourist flows and tourism costs	/	$A = \frac{V}{C}$

By constructing the following objective function, we can optimize tourism management in Barcelona:

Objectives： Maximize R − C − E − P

Constraints:

Table 5: constraint condition

Symbol	Description	constraint condition
S	tourist satisfaction	$S \geq 3$
L	Resident	$L \geq 3$
E	sentiment Environmental	$E \leq E_{max}$
P	impact Infrastructure pressure	$P \leq P_{max}$

5.3 A Computational Example of the Introduction of the Sustainability Comprehensive Evaluation Model in Barcelona's Tourism Industry

Let's say that Barcelona received 30 million visitors in 2019 to make some preliminary calculations:

$$\text{Revenue (R)}: R = 30{,}000{,}000 \times 300 = 9{,}000{,}000{,}000€$$

$$\text{Cost (C)}: C = 30{,}000{,}000 \times 50 = 1{,}500{,}000{,}000€$$

$$\text{Environmental impact (E)}: E = 30{,}000{,}000 \times 0.5 = 15{,}000{,}000 tCO2$$

Infrastructure pressure (P): Assuming that the maximum carrying capacity of infrastructure is 50 million tourists.

$$\text{Tourist satisfaction (S)}: S = 10 - \left(\frac{1{,}500{,}000{,}000}{30{,}000{,}000 \times 100}\right) = 10 - 5 = 5$$

$$\text{Residents' emotions (L)}: L = 5 - \left(\frac{0.6}{30{,}000{,}000}\right) - \left(\frac{15{,}000{,}000}{30{,}000{,}000}\right) = 5 - 0.00002 - 0.5 = 4.49998$$

The sentiment of residents is relatively positive, but it is still necessary to pay attention to the impact of environment and infrastructure on residents.

5.4 Barcelona tourism industry policy suggestions

Based on the results of the model, the following are policy recommendations for sustainable tourism in Barcelona:

Increase in tourist taxes and fees (T): A moderate increase in tourist taxes can help increase Barcelona's revenue and be used for infrastructure construction and environmental protection. By increasing revenue from taxes and fees, the burden of infrastructure and environmental impacts can be reduced.

Optimization of management costs (C): Reasonable control of tourist management costs, optimization of infrastructure construction and maintenance strategies, to ensure that tourist satisfaction (S) is improved.

Increase investment in environmental protection (I): Reduce the environmental impact of each tourist (E) by increasing investment in environmental protection, so as to keep the environmental impact under control and improve the satisfaction of tourists and residents.

Limiting the number of tourists (V): Implementing flow restrictions when the flow of tourists is too large ensures that Barcelona's infrastructure (P) and environment (E) are not overloaded, thereby increasing the satisfaction of residents (L).

Promote alternative attractions (A): Develop less crowded alternative attractions, such as the natural attractions around Barcelona, to divert tourists and reduce the pressure on popular attractions.

Through these measures, Barcelona can achieve the growth of tourism revenue, while reducing environmental and infrastructure pressure, improving the satisfaction of residents and tourists, and achieving sustainable tourism development.

Table 7: TREND: Weighing Both Positive and Negative Impacts

	1998	2002	2006	2021	2022	2023	Change 2022-23
Positive impacts outweigh negative (1998-2006: benefits outweigh costs)	45	46	47	51	49	38	-11
Negative impacts outweigh positive (1998-2006: costs outweigh benefits)	32	29	32	30	32	25	-7
Neutral/neither	16	16	14	14	12	30	+18
Don't know	6	8	7	4	5	4	-1

Respondents saying the positive outweighs the negative dropped from 49% in 2022 to 38% in 2023, while those saying the negative outweighs the positive also dropped, from 32% to 25%, although the latter shift was not statistically significant. The biggest change was in those saying neutral or neither: from 12% in 2022 to 30% in 2023.

6. Model Evaluation and Further Discussion

6.1 Strengths

1. Multidimensional Optimization:

By integrating fuzzy comprehensive evaluation, entropy weighting method, and grey relational analysis, the model is able to comprehensively consider various factors impacting sustainable tourism, such as visitor numbers, revenue, environmental impact, and infrastructure capacity, ensuring a holistic optimization approach.

2. Data-Driven Approach:

The model employs a data-driven analysis method that objectively reflects the current state and changes in various indicators, making the decision-making process more scientific and transparent.

3. High Adaptability:

The model is not only applicable to Juneau but also exhibits strong scalability and adaptability, making it suitable for other destinations affected by overtourism, especially environmentally sensitive regions.

4. Sensitivity Analysis:

The model conducts sensitivity analysis on key factors, helping to identify which elements are most critical to the sustainability of the tourism industry, thereby enabling more targeted policy adjustments.

6.2 Weaknesses

1. Data Dependency:

The effectiveness of the model heavily relies on the accuracy and completeness of the data. A lack of high-quality data may affect the model's predictive accuracy and practical applicability.

2. Complexity:

The model's design is relatively complex, involving multiple algorithms and steps, which may require a high level of technical expertise for implementation and operation. This could pose challenges for local governments or decision-makers in understanding and applying the model.

3. Localized Data Limitations:

While the model has strong adaptability, it is based on data and assumptions specific to Juneau, which may not fully apply to other destinations with differing socio-economic conditions, cultural backgrounds, and tourism characteristics.

6.3 Further Discussion

6.3.1 Model Improvement

Data Collection and Updating: The current model primarily relies on historical data for analysis. However, with changing tourism trends, especially during the post-pandemic recovery period, the timeliness and accuracy of the data have become critical. To enhance the model's accuracy, real-time data collection mechanisms can be incorporated, using technologies such as sensors and social media analytics to track visitor numbers, behaviors, and environmental changes in real time. This approach will provide more precise input data for the model.

Dynamic Weight Adjustment: The model currently uses a fixed weighting system (e.g., entropy weight method) to assess the impact of various indicators. However, sustainability in tourism is a dynamic process, and the relative importance of environmental, social, and economic factors can change over time. For instance, in the early stages of tourism recovery, economic benefits may be prioritized, while later, environmental protection and social impacts might become more critical. To better accommodate different phases and scenarios, the model can integrate a dynamic weight adjustment mechanism, allowing the weights of indicators to be modified based on changing conditions.

Considering Uncertainty Factors: The tourism industry faces numerous uncertainties, such as natural disasters, policy changes, and market fluctuations, which are often difficult to quantify and predict. To improve the model, methods like Monte Carlo simulations can be introduced to account for these unpredictable factors, allowing for a more comprehensive assessment of tourism sustainability by modeling various uncertainties.

6.3.2 Model Extension

Cross-Regional Tourism Planning: The current model focuses on a single destination (Juneau). However, tourism sustainability is not only influenced by a single region but also by neighboring or cross-regional tourism flows. Therefore, the model can be expanded to include elements of cross-regional tourism planning, considering factors such as the movement of tourists between different areas, resource sharing across regions, and policy coordination. This comprehensive approach to sustainable tourism development is particularly important for regions like Alaska, which has multiple tourism destinations.

Incorporating Social Perception and Participation Mechanisms: In assessing social sustainability, the model currently considers indicators such as local sentiment, cost of living, and satisfaction. However, it overlooks the role of community participation and social perception in tourism development. To increase the model's comprehensiveness, social participation mechanisms can be integrated. By conducting surveys and gathering data, the attitudes and opinions of local residents and tourists toward tourism projects can be understood, ensuring that their needs and expectations are included in the decision-making process.

Sustainability Assessment and Climate Change: Climate change is increasingly affecting the tourism industry, particularly for destinations reliant on natural landscapes and resources. To make the model more robust, climate change adaptation assessments can be introduced to simulate tourism sustainability under different climate scenarios. For instance, with rising temperatures, certain tourist activities may face the risk of disappearing, while new activities could emerge as main attractions. The model should therefore take into account the impacts of climate change on various tourism activities and resources, allowing for the prediction of potential risks and opportunities in advance.

7. Conclusion

In this study, we developed and optimized a model for sustainable tourism in Juneau, Alaska, incorporating methods such as Fuzzy Comprehensive Evaluation, Entropy Weight Method, and Grey Relational Analysis. The aim of this research is to balance the economic, environmental, and social sustainability of tourism, providing strong support for tourism management decision-making.

The key findings of the study are as follows:

- The Fuzzy Comprehensive Evaluation method effectively handles the multidimensional complexity of tourism sustainability by considering factors such as visitor numbers, infrastructure, and environmental impact, enabling decision-makers to assess sustainability more comprehensively.
- The Entropy Weight Method plays a crucial role in the model by automatically calculating weights based on the information contribution of each indicator, ensuring that the most influential factors are appropriately prioritized.
- Through Grey Relational Analysis, we revealed the interrelationships between various factors affecting sustainable tourism development, helping to identify key drivers and their interactions. This provides valuable insights for balancing economic growth with environmental and social sustainability.
- Sensitivity analysis demonstrated that the model is robust to small changes in key parameters, confirming its adaptability to different scenarios and helping assess its applicability at larger scales or in other regions.

The main insight from this research is that sustainable tourism development is not just about maximizing economic benefits, but also about minimizing environmental impacts and ensuring social equity. A comprehensive consideration of the economic, environmental, and social dimensions of sustainability is crucial for tourism planning. The model developed in this study provides a powerful tool for balancing these objectives, offering a reference for developing sustainable strategies in Juneau and other similar destinations.

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