No Longer a Burden: a Sustainable Tourism Model

Summary

Japanese photographer Yojiro Hoshino once poetically referred to Alaska as "the last pristine land of wildlife," and indeed it is. As one of the few regions in the world that has not been polluted by heavy industry, Alaska's glaciers, tundras, and whales attract a large number of tourists from around the globe to travel here. However, the influx of tourists has brought about overcrowding and the gradual decline of glaciers, causing considerable pressure on local facilities and the natural environment. To better coordinate tourism, local resident facilities, and the natural environment, we have established relevant models, determined the distribution of additional income, and provided effective methods for improving local tourism.

We have established a sustainable tourism evaluation model to analyze this, which mainly includes four parts: tourism revenue, carbon emissions, infrastructure stress, and local resident satisfaction, and respectively elaborated on the impact of the distribution of additional income (government investment) on each part. These four parts are interrelated, and we use weights (w_1~w_4) to represent their impact on the objective function. After establishing the objective function, we used the genetic algorithm to calculate the optimal point of the objective function and obtained the most ideal number of tourists under the current environment.

Through sensitivity analysis of the relevant weights, the model is relatively stable. At the same time, we found that the adjustment of resident satisfaction has the greatest impact on the objective function. In addition, using additional income to protect the environment and improve resident satisfaction can maximize the improvement of local tourism benefits.We applied this model to another city by changing the values of the relevant parameters in the formula. At the same time, according to the type of scenic spots in the city, we added additional relevant variables to the evaluation function to improve the model. For example, maintenance costs were added to ancient architectural scenic spots, and further impacts on the ecological environment were added to nature reserves. Taking Dubrovnik as an example, we analyzed in detail the additional variables that need to be added to each scenic spot during the analysis and their impact on the objective function.For the problem of uneven distribution of the number of tourists in scenic spots, we used the Logistic model to analyze the impact of government publicity investment on the number of tourists in scenic spots. By reasonably publicizing and improving facilities for each scenic spot based on the current number of tourists, we can balance the number of tourists in each scenic spot to maximize tourism benefits. Based on the above model, we have revealed the key factors affecting local tourism and put forward relevant policies to promote the progress of tourism.

Keywords: Sustainable tourism; Logistic model; Policy-making

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1 Introduction

1.1 Problem Background

Juneau, Alaska, with a population of around 30,000, has seen a significant rise in tourism, especially cruise ship tourism. In 2023, it welcomed 1.6 million cruise passengers, which brought about $375 million in direct spending, supported 3,850 jobs, and generated $196 million in labor income.

However, this growth has caused problems. Overcrowding at attractions like Mendenhall Glacier affected 63% of residents in 2023. Vehicle congestion downtown and on sidewalks was a major issue for 61% and 59% of residents respectively. Environmental concerns, such as cruise ship air emissions, impacted 60% of residents. The local transportation system and housing affordability have also been affected, and some locals are dissatisfied. A 2023 survey showed 11% of residents reported a negative overall impact of tourism on their households, and 50% preferred fewer cruise passengers in the future.

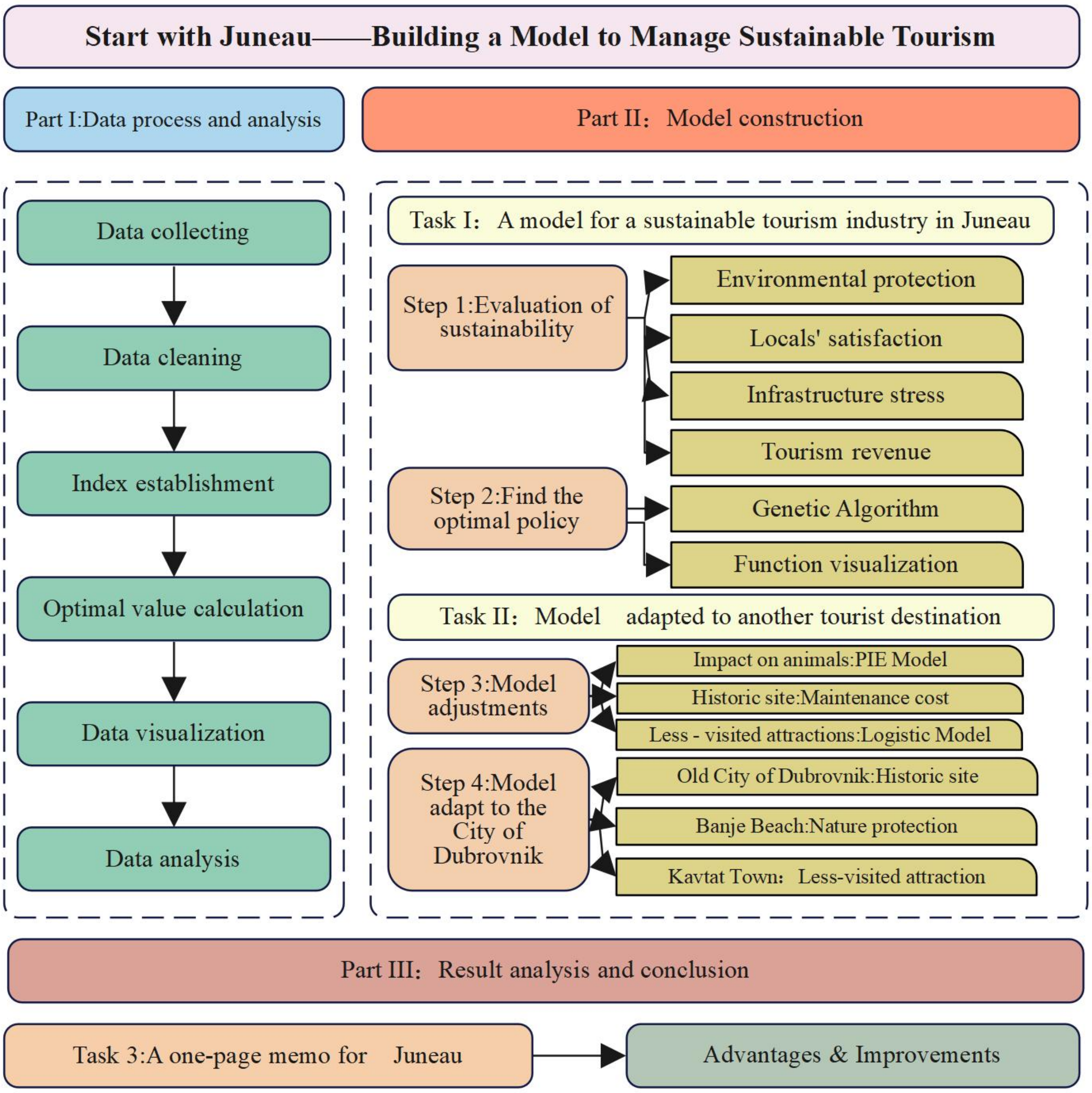
Therefore, it is urgent to develop a model and adopt scientific measures to achieve a sustainable tourism industry in Juneau.

1.2 Restatement of the Problem

The ultimate goal is to develop and implement a sustainable tourism plan for Juneau, Alaska. The plan should mitigate the negative impacts of over-tourism while maintaining and enhancing its economic benefits. Specifically, it aims to balance the number of tourists with the carrying capacity of the environment and infrastructure, protect local ecological and cultural resources, meet the needs of the local community, and ensure the long - term stable development of the tourism industry.

The goal can be divided into three sections. The first is to build a model for the sustainable tourism industry. We need to comprehensively consider factors such as the number of visitors, overall revenue, and measures to stabilize tourism, determine the optimized and constrained factors, and rationally plan the expenditure of additional revenue. The second part is to apply this model to other tourist destinations affected by over-tourism. Adjust the measures according to the characteristics of different locations to promote the balanced distribution of tourism resources. The third is to provide a concise and forward - looking proposal to the Juneau Tourism Council, covering predictions about the future of tourism, the effectiveness evaluation of various measures, and strategies for optimizing the results.

1.3 Our Work



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Memo to the Tourist Council of Juneau

In recent years, the number of tourists in Juneau has grown rapidly, bringing significant economic benefits but also impacting the lives of local residents and causing some environmental damage. This memo aims to analyze the current state of Juneau's tourism based on our sustainable tourism model and propose suggestions for further improving the tourism industry in the future.

According to our sustainable tourism model, if the number of tourists is allowed to grow naturally without restrictions, the pressure on local infrastructure and carbon emissions will increase significantly, leading to a 40% to 50% reduction in the number of glaciers within five years, which will have a significant impact on the tourism industry. Meanwhile, a significant increase in the number of tourists will reduce the satisfaction of local residents, and may even lead to protests and demonstrations. If the number of tourists is appropriately restricted, the pressure on natural environments such as glaciers will be particularly reduced. Although there will certainly be a decrease in tourism revenue, the positive effect is significant according to the evaluation function we have established.

In terms of measures, the policies currently adopted by the local government are feasible, but further analysis of their relevance is needed. The additional revenue generated by increasing hotel taxes and tourist fees is effective in alleviating glacier recession and infrastructure pressure. However, it is undeniable that the number of tourists will decrease with the increase of additional charges. We need to balance the charging amount and the number of tourists to alleviate environmental and infrastructure pressure as much as possible without affecting the economy.

Based on the analysis of the model, we propose the following optimization policies:

- Tourism Resource Expansion Policy: The government should develop more new tourism resources locally to appropriately alleviate the passenger flow of glacier attractions and reduce the pressure on classics. It is possible to explore local cultural tourism resources, such as Eskimo villages and alleviate the problem of glacier recession.
- Tourism Seasonality Regulation Policy: In terms of publicity, increase the promotion of off-season tourism and formulate characteristic tourism publicity plans for different seasons. As for price regulation, implement off-season preferential policies, and provide discount preferences for scenic spot tickets, hotel accommodation, transportation and other fees. Meanwhile, plan and construct infrastructure reasonably to improve the capacity of infrastructure during the peak season, such as increasing the capacity of public transportation, building temporary parking lots, etc., to alleviate the pressure on infrastructure during the peak season. In addition, implement passenger flow control during the peak season.
- Comprehensive Supervision and Assessment Policy: Establish a unified tourism supervision agency to comprehensively supervise various attractions. Formulate a complete set of tourism industry standards and regulations, covering multiple aspects such as environment, cultural heritage protection, and service quality, and impose penalties on tourism enterprises and individuals who violate the regulations. Regularly assess the development of tourism, analyze the sustainability of tourism development based on the total objective function and various monitoring indicators.

2 Notations

The key mathematical notations used in this paper are listed in Table 1.

Table 1: Notations used in this paper

Symbols	*Definition*
$\mathbf{V}$	The volume of tourists
$\mathbf{V_{limit}}$	The limitation of $\mathbf{V}$
$\mathbf{R}$	The per tourists consumption amount
$\mathbf{I}$	The index of tourism revenue
$\mathbf{C}$	The index of carbon footprint
$\mathbf{F}$	The index of Infrastructure stress
$\mathbf{S}$	The index of the residents' satisfaction
$\mathbf{E_1}$	Government expenditure on the environment
$\mathbf{E_2}$	Government expenditure on infrastructure
$\mathbf{E_3}$	Government expenditure on community services
$\mathbf{P}$	The index of overall profit
$\mathbf{V_i}$	The volume of tourists on the i-th scenic spot
$\mathbf{V_{i,limit}}$	The limitation of $\mathbf{V_i}$
$\mathbf{R_i}$	The average consumption amount
$\mathbf{I_i}$	The index of tourism revenue
$\mathbf{C_i}$	The index of carbon footprint
$\mathbf{F_i}$	The index of Infrastructure stress
$\mathbf{S_i}$	The index of the residents' satisfaction
$\mathbf{E_{i1}}$	Expenditure on the environment
$\mathbf{E_{i2}}$	Expenditure on infrastructure
$\mathbf{E_{i3}}$	Expenditure on community services of the i-th scenic spot
$\mathbf{E_{i4}}$	Government expenditure on advertising
$\mathbf{P_i}$	The index of overall profit

3 Model Design

3.1 Basic Model

We construct a sustainable tourism industry model with four sections, including , environment protection and local's satisfaction value. The sections interact with each other through various variables. Each section is valued by a score to indicate its performances. Higher scores indicate more sustainable and healthier section performances. With the scores of all four sections, we then calculate a final score that evaluates the performance of the entire model. Each policy under consideration is described through interactions between the variables of different sections. With the objective of maximizing the total score and using genetic algorithms, we calculated the optimal allocation strategy for the taxes in the economic section as well as the optimal number of tourists.

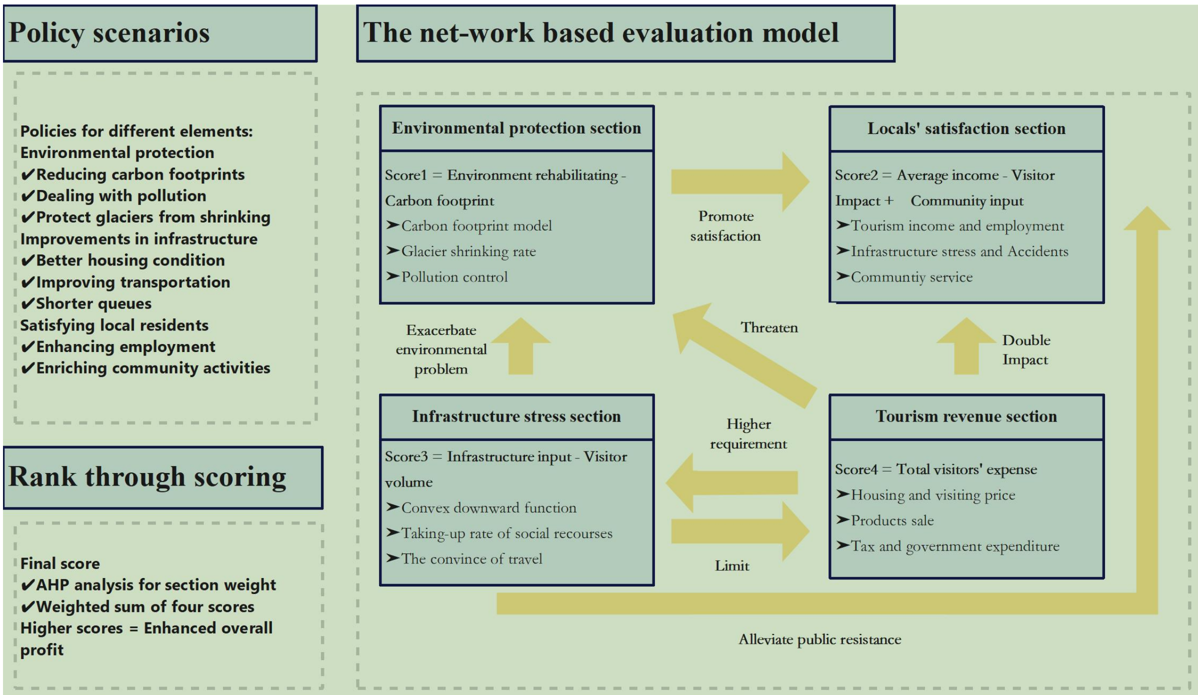


Figure 1. *Flowchart of the net-work based evaluation model*

3.1.1 The Tourism Revenue Section

1) Modeling ideas

Tourism revenue primarily comes from direct tourist spending on accommodations, dining, transportation, and attractions. This income significantly impacts local economies by creating jobs, boosting business revenues, and funding infrastructure improvements. Additionally, it can enhance the quality of life for residents through increased public services and economic stability.

2) Supplementary assumptions and justifications

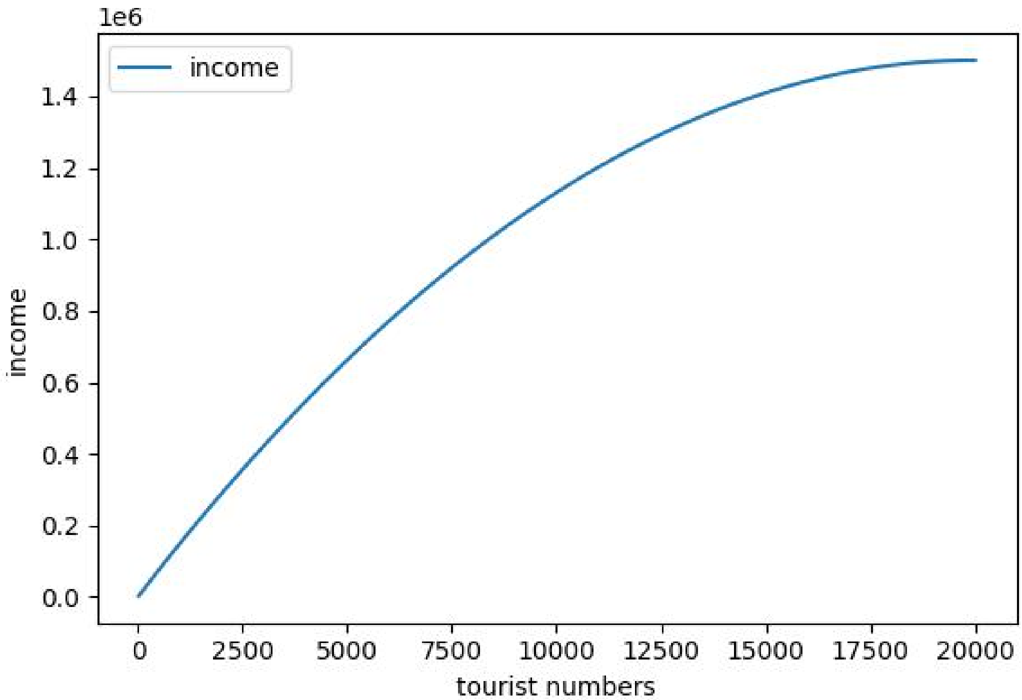
● When calculating tourism revenue, we only consider the income generated from direct tourist consumption or additional fees paid by tourists. This is because taxes generated outside of consumption are no longer within the scope of tourism discussions, are difficult to tally and reinvest, and are less perceptible to the public, having a smaller impact on social satisfaction. In our model, this part can be excluded from the discussion.

3) Calculations

When the number of tourists increases to a certain level, the reception capacity of the scenic spot will be limited, and the growth rate of tourism revenue will gradually slow down. At this time, a non-linear model can be used.

$$I(V) = V \times R(1 - t * V/V_{limit})$$

Below is the image of I as a function of V



As is be shown below, additional tax coming from this part of revenue will be reinvested in tourism-related affairs.

3.1.2 The Environmental Protection Section

1) Modeling ideas

We use carbon footprint and pollution index separately to measure the effectiveness of environmental protection. The combination of the two factors allows us to grasp a fuller picture of the real condition of the local environment. To be specific, we can avoid situations where carbon footprint is controlled at the cost of more pollution, or vice versa. Moreover, to improve model realism, we considered the rehabilitating of the local ecosystem under natural conditions. As for the pollution index, we take the content.

2) Supplementary assumptions and justifications

- When considering carbon footprint, we assume that a typical tourist generates the same amount of CO_2 every day as a local does, given that tourists are under the same living condition as the locals. Transportation carbon emissions account for the largest share of all carbon emissions caused by travelling.

3) Calculations

A) **Carbon footprint**

Assuming that each tourist generates a certain amount of carbon emissions during the travel process, and this part of the carbon emissions is directly proportional to the number of tourists. At the same time, considering the scale effect or synergy brought by the increase in the number of tourists. For example, when the number of tourists is relatively large, it may lead to traffic congestion, increased energy consumption and other phenomena, which will make the increase speed of carbon emissions exceed the linear relationship. This non-linear relationship can be approximately described by a quadratic term. Therefore, we can obtain the basic form of the carbon emission function.

$$C_0(V) = \alpha V + \beta V^2$$

B) Pollution evaluation

When calculating the annual pollution caused by tourism in Juneau,other pollutants are converted into the carbon emissions required to eliminate them, mainly to simplify the calculation process and provide a unified quantification standard.This conversion method can transform different types of pollution(such as solid waste,wastewater, air pollutants, etc.)into a common measurement indicator-carbon emission equivalents, thereby facilitating comparison and assessment. In addition, as a core indicator of global environmental issues, carbon emissions have high attention and policy relevance.Through conversion,the overall environmental impact of tourism can be more intuitively reflected,and a basis for formulating emission reduction strategies can be provided.

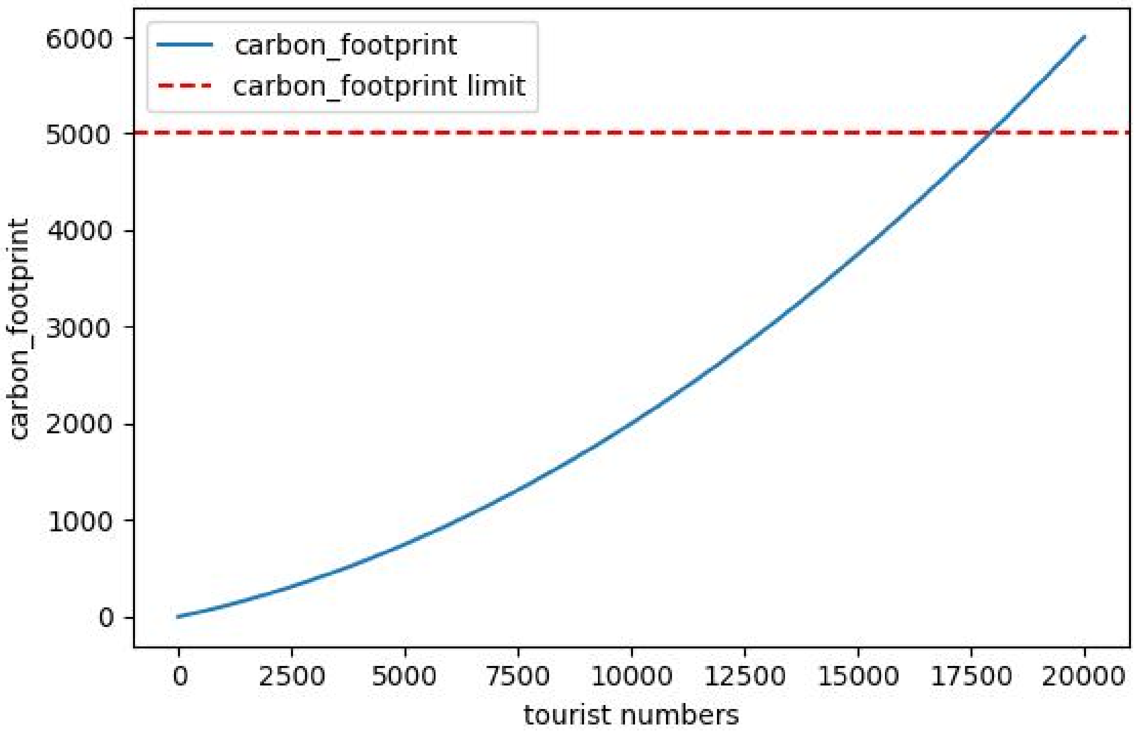
$$C(V) = C_0(V) + \epsilon V = (\alpha + \epsilon)V + \beta V^2$$

Considering government's expenditure on environment:

$$E_1 = \lambda_1 I$$

$$C = C(V) - \mu_1 E_1$$

Below is the image of C as a function of V



3.1.3 The Infrastructure Load Section

1) Modeling ideas

When calculating the infrastructure load caused by tourism, both infrastructure investment and tourism consumption must be considered. Infrastructure investment determines the capacity to support tourism activities, while tourism consumption reflects the actual use of infrastructure. Considering both provides a comprehensive view of the load and aids in effective planning and management.

2) Supplementary assumptions and justifications

When calculating infrastructure load, focusing on tourist numbers rather than local activities is justified because tourists typically use infrastructure at a much higher rate than locals, especially during peak seasons. This leads to a more pronounced impact on infrastructure load. Additionally, local residents' use of infrastructure is relatively stable and predictable, falling within the normal operational capacity of the system.

3) Calculations

The infrastructure load can be estimated by considering the direct impact of each tourist and the additional strain caused by the cumulative effects of a larger number of tourists.

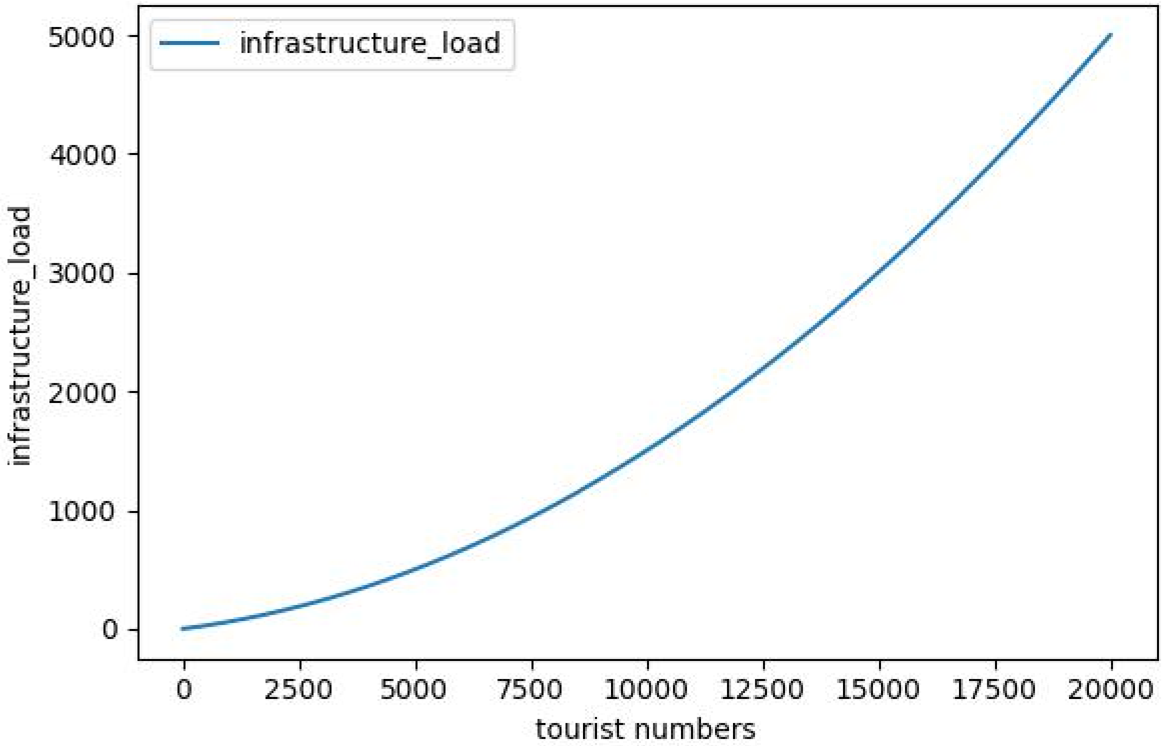
$$F(V) = \gamma V + \delta V^2$$

Considering government's expenditure on infrastructure:

$$E_2 = \lambda_2 I$$

$$F = F(V) - \mu_2 E_2$$

Below is the image of F as a function of V



3.1.4 The Local's Satisfaction Section

1) Modeling ideas

Infrastructure load (E_1) directly affects the quality of daily life for residents, as issues like traffic congestion and utility supply can lead to decreased satisfaction. Carbon emissions (C) not only impact environmental quality but also raise health and quality of life concerns among residents, potentially lowering satisfaction. While increased tourism revenue can enhance economic welfare through job creation and improved living standards, thereby increasing satisfaction, a rise in tourist numbers (V) can strain infrastructure, degrade environmental quality, and increase living costs, which may offset the positive economic effects and reduce resident satisfaction. Therefore all three factors above should be considered in our model.[1]

2) Supplementary assumptions and justifications

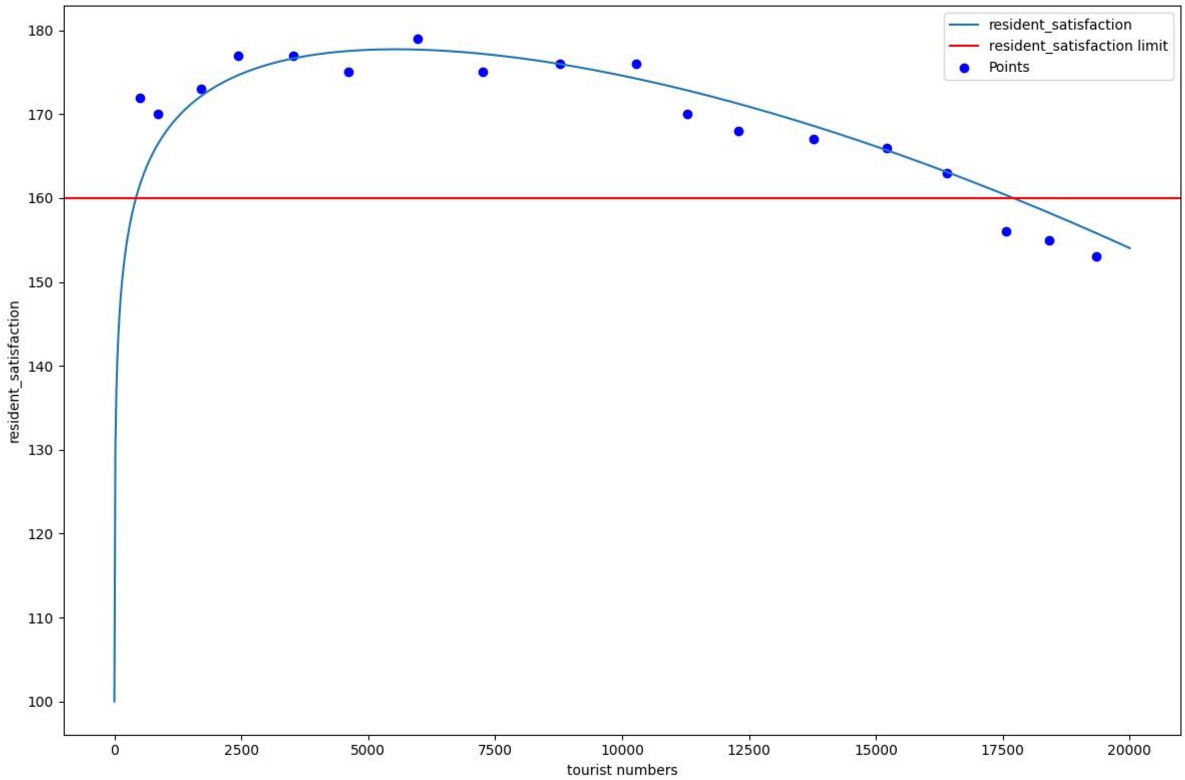
The assumption that infrastructure load (F) is only related to the number of tourists (V) is supported by empirical studies. For example, a study titled "A 'load-carrier' perspective approach for assessing tourism resource carrying capacity" found that an increase in tourist numbers led to a significant rise in infrastructure load, particularly in transportation and utility services. Another study, "Analysis of temporal and spatial evolution of tourism resource carrying capacity performance in China," used a "Load-Carrier" method to evaluate the tourism resource carrying capacity (TRCC) across 30 provinces in China from 2008 to 2019, highlighting the direct impact of tourist numbers on infrastructure load. These studies demonstrate that the influx of tourists is a primary driver of increased infrastructure load, justifying the assumption in the context of tourism-related infrastructure analysis.

3) Calculations

We have collected the changes in resident satisfaction under different numbers of tourists in the same city and fitted the estimation formula below.

$$S(V) = S_0 + \eta \log(1 + V) - \zeta V - k \times F$$

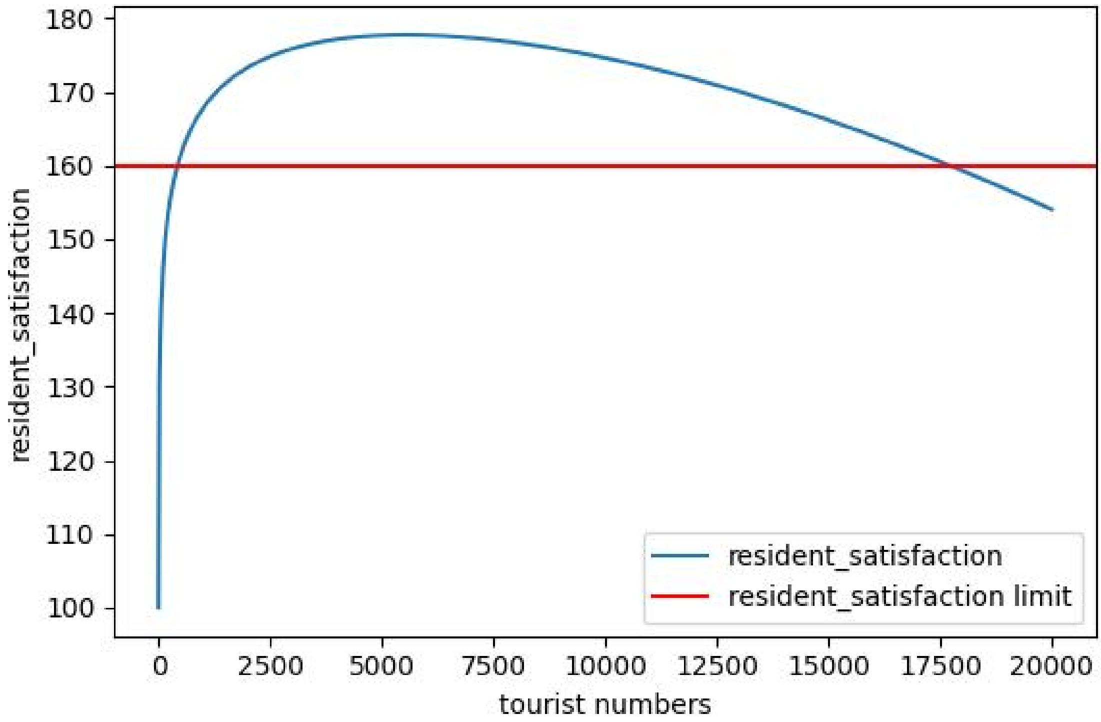
The following figure shows the closeness between our estimation formula and the original data.[2]



Considering government's expenditure on community projects:

$$S = R(V) + \mu_3 E_3$$

Below is the image of S as a function of V



3.1.5 Target Value

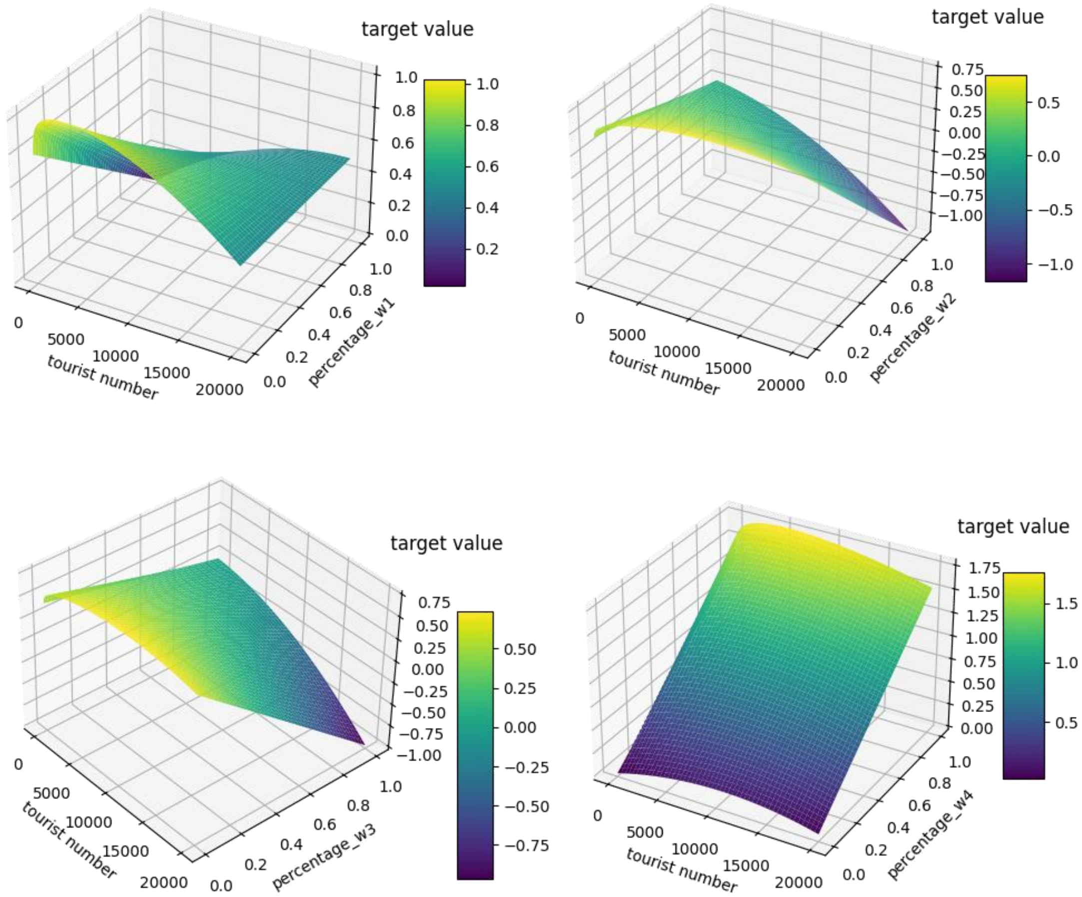
We use $w_{1\sim4}$ to represent the importance of tourism revenue, carbon emissions, infrastructure, and resident satisfaction, respectively. By calculating the ratio of these quantities to their corresponding maximum values to eliminate units, we obtain the final evaluation value, which reflects how's the model doing under the current number of tourists and revenue allocation.

$$P = w_1 \times \frac{I}{V_{limit} \times R} - w_2 \times \frac{C}{C_{limit}} - w_3 \times \frac{F}{F(V_{limit})} + w_4 \times \frac{S}{S_0}$$

3.1.6 Sensitivity Analysis

A)Weight sensitivity analysis

As mentioned in the previous section, we use multi-level analysis to comprehensively evaluate the tourism coefficient of the entire Juneau city, and the value of the objective function largely depends on the weight allocation of w_1 to w_4. To assess the accuracy of the results, we try to change the weight allocation, taking w_1 to w_4 as independent variables respectively, and the remaining three variables are allocated according to the original proportion, ensuring that $w_1+w_2+w_3+w_4=1$ always holds, and draw a three-dimensional coordinate graph of the objective function with the number of tourists and weight allocation, to compare the relative importance of the four factors in affecting the objective function.



As can be seen from the graph, the adjustment of resident satisfaction (with a weight of w_4) has the greatest relative impact on the objective function, followed by tourism revenue. Since the fitting coefficients of environmental factors and facility pressure are similar, the adjustment of their weights has a consistent impact on the objective function.

B) Parameter sensitivity analysis

Our model can flexibly adjust parameters according to different cities and attractions to adapt to local conditions. In this part of our analysis, we mainly analyze the sensitivity of the upper and lower limits of each indicator.

Through the analysis of the formula, it is plain to see that appropriately increasing the carrying capacity of infrastructure can increase the number of tourists, while the impact on carbon emissions and resident satisfaction is relatively small, which is conducive to the further development of the tourism industry, and the change in carrying capacity has a relatively small impact on the extreme value of the objective function. However, the lower limit of resident satisfaction and the upper limit of carbon emissions have a particularly significant impact on the extreme value of the objective function, which reminds us that improving the local environment and increasing the satisfaction of local residents are the keys to improving tourism benefits.

3.2 Advanced Model

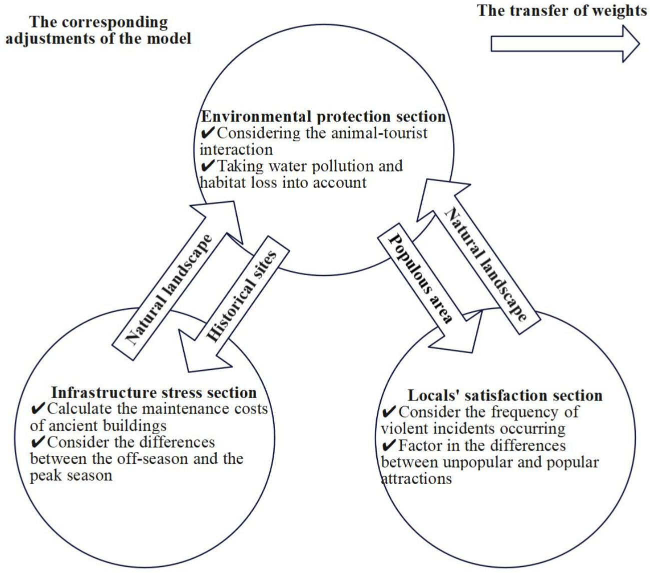


Figure 2. *Flowchart of the advanced model*

To apply the sustainable tourism model of Juneau to other destinations affected by over-tourism, it is necessary to adjust and optimize the model in combination with the characteristics of the new destination.

3.2.1 Environmental aspects

1) Modeling Idea

Measure the level of pollution caused by tourism activities and its impact on the environment, and incorporate the pollution issue into the sustainable tourism model in order to assess and control the negative effects of tourism development on the environment and promote sustainable development. For scenic spots in nature reserves, the impacts of tourism activities on scenic spots' biodiversity are assessed, and measures and targets for biodiversity conservation are identified to provide a quantitative basis for sustainable tourism development in terms of biodiversity conservation.

2) Supplementary assumptions and justifications

the amount of pollution from tourism activities is positively correlated with the number of tourists. For example, in Phuket, Thailand, the peak tourist season sees a significant increase in garbage and sewage, leading to environmental degradation.[3]

3) Calculation

A)Pollution

Pollution index as $Pollution_i$ and the formula can be constructed as

$$Pollution_i = \varphi_i V_i + \omega_i V_i^2$$

Among them φ_i and ω_i are the parameters determined according to the scenic spot's own characteristics (such as the area of the scenic spot, the self-restoration of the environment, etc.).

B) Biodiversity conservation issues

Biodiversity index as $Biodiversity_i$, the original area of the habitat be $Area_{original}$, and the area reduced due to tourism activities be $Area_{reduce}$, which gives us

$$Biodiversity_i = \frac{Area_{original} - Area_{reduce}(V_i)}{Area_{original}}$$

Among them, $Area_{reduce}(V_i) = \alpha_i V_i + \beta_i V_i^2$, α_i and β_i are parameters determined according to the ecological characteristics of the scenic area, reflecting the degree of influence of the number of tourists on the reduction of the area of biological habitats.

Calculating negative interactions between tourists and wildlife (PIE)

$$PIE = \rho_{wildlife} \times \frac{V_i}{N + V_i - 1} + \rho_{tourists} \times \frac{N}{N + V_i - 1} \approx \frac{2V_i N}{(V_i + N)^2}$$

Where V_i is the number of tourists in the area, N is the total number of wildlife populations, $\rho_{wildlife}$ is the wildlife density, $\rho_{tourists}$ is the tourist density . Wildlife density

$$\rho_{wildlife} = \frac{N}{N + V_i}$$

Visitor density

$$\rho_{tourists} = \frac{V_i}{N + V_i}$$

C) Model adjustment:

For the corresponding scenic spots, the pollution index $Pollution_i$ and the biodiversity index $Biodiversity_i$ are included in the overall objective function. Consider the impact of these two indices when calculating the overall sustainable tourism evaluation index. For example, when calculating the overall environmental impact, the weights $w_{pollution}$ and $w_{biodiversity}$ can be set to update the calculation of the comprehensive environmental impact index

$$E_i^{'} = E_i - w_{pollution} Pollution_i + w_{biodiversity}(Biodiversity_i - PIE)$$

Then $E_i^{'}$ is substituted into the objective function of the attraction as an environmental indicator to assess the sustainable development status of the scenic spot, in order to reflect the comprehensive impact of tourism activities on the environment more comprehensively.

3.2.2 Cultural heritage aspects

1) Modeling Idea

To clarify the relationship between the maintenance cost of cultural and tourism venues and the intensity of tourism activities, to provide a basis for the rational arrangement of maintenance funds and the protection of cultural heritage, and to ensure the sustainable use of cultural and tourism venues.

2) Additional assumptions and justifications

It is assumed that the maintenance costs of cultural tourism venues are positively correlated with the number of tourists and the frequency of venue use. With the increase in the number of tourists and the frequency of use of the venue, the wear and tear of the buildings and facilities of cultural tourism venues will intensify, requiring more frequent maintenance and restoration work, which will lead to an increase in maintenance costs. For example, some popular historical monuments, due to the large number of tourists visiting them, their internal floors and walls are easily damaged, and the maintenance costs have increased significantly.

3) Calculation

The maintenance cost of cultural and tourist places as $Mcost_i$which can be expressed as

$$Mcost_i = \gamma_i V_i + \delta_i F(V_i)$$

Where γ_i is a cost coefficient directly related to the number of visitors, and $F(V_i)$ is an index of infrastructure pressure on the site.

4) Model Adjustment

Include the cost of maintaining cultural tourism venues$Mcost_i$ in the economy. When calculating the overall economic benefits,$V_i \times R_i$ can be considered by including$Mcost_i$ in the tourism benefits component and in the costs component to

$$I_i^{'} = I_i - Mcost_i$$

ReplacingI_i in the original objective function makes the model more accurately reflect the economic benefits and sustainability of cultural heritage tourism.

3.2.3 The problem of seasonal popularity in scenic areas

1) Modeling idea

To quantify the impact of seasonal popularity differences in scenic spots on infrastructure pressure and resident satisfaction, and to provide data support for the development of rational tourism planning and management strategies to mitigate the negative impacts of seasonal tourism.

2) Supplementary assumptions and justifications

It is assumed that the pressure on infrastructure and the probability of occurrence of vicious events in the scenic spot during the peak season (V_{hot}) is higher than that during the off-season (V_{cold}), and it is related to the difference in the number of tourists; it is assumed that the peak season and the off-season each take up half of the time, taking the summer half year and the winter half year as an example. In the peak season, a large number of tourists flock to scenic spots, which exceeds the capacity of the infrastructure, leading to traffic congestion, accommodation tension and other problems, and at the same time, the density of people also increases the probability of vicious incidents (e.g. law and order problems, conflict incidents, etc.).

3) Calculation

Let the infrastructure stress index be F_{hot} in the high season and F_{cold} in the low season, which yields ($k = V_{hot}/V_{cold}$)

$$F_{hot} = \gamma_i V_i \times \frac{2k}{1+k} + \delta_i V_i^2 \times (\frac{2k}{1+k})^2$$
$$F_{cold} = \gamma_i V_i \times \frac{2}{1+k} + \delta_i V_i^2 \times (\frac{2}{1+k})^2$$
$$F'(V_i) = \gamma_i V_i + \delta_i V_i^2 \times 2\frac{1+k^2}{(1+k)^2}$$
$$F'_i = F'(V_i)$$

Among them, δ_i and γ_i are parameters determined according to factors such as the condition of scenic area infrastructure and the level of security management, reflecting the degree of impact of differences in the number of tourists on the pressure on infrastructure.

3.2.4 Possible governmental regulatory initiatives

1) Modeling idea

To simulate the impact of government regulation measures on seasonal heat differences in scenic spots, to assess the effects of different regulation strategies, and to provide a decision-making basis for the government to formulate scientific and effective tourism regulation policies.[1]

2) Additional assumptions and justifications

It is assumed that the government can influence the distribution of tourists in different seasons through measures such as publicity investment (E_{i4}) and price regulation ($PriceAdjustment$). Referring to the Research on the Impact of Government Intervention on Tourism Seasonal Balance, the government increases the promotion of off-season tourism and introduces off-season incentives, which can attract more tourists to visit scenic spots in the off-season.

3) Calculation

Let the number of tourists in the regulated high season be$V_{hot-adjusted}$ and the number of tourists in the low season be$V_{cold-adjusted}$, then

$$V_{hot-adjusted} = V_{hot} - \omega_1 E_{i4} - \omega_2 PriceAdjustment$$
$$V_{cold-adjusted} = V_{cold} + \omega_3 E_{i4} + \omega_4 PriceAdjustment$$

The parametersω_1 ,ω_2 ,ω_3 ,ω_4 are parameters based on the effects of government regulatory measures, reflecting the extent to which promotional investment and price regulation affect the distribution of tourist arrivals in different seasons.

4) Model Adjustment

Substitute the adjusted tourist numbers$V_{hot-adjusted}$ and$V_{cold-adjusted}$ into the formulas related to tourist numbers in the original model, such as the formulas for the carbon emission index, the infrastructure pressure index, and the tourism revenue index. At the same time, when calculating the overall sustainable tourism evaluation indexes, the combined effects of seasonal factors on these indexes are considered. When calculating the infrastructure pressure index for the whole year, a weighted average of$F_{hot-adjusted}$ and$F_{cold-adjusted}$ is made according to the length of the peak season and the off-season, and then substituted into the overall objective function, so as to make the model more in line with the actual situation of seasonal tourism in scenic spots.

3.2.5 Impact of government investment in publicity on the number of visitors to cold spots (Logistic model)

1) Modeling Idea

Use Logistic model to describe the process of government publicity investment on the number of tourists in cold spots, analyze the growth trend of the number of tourists with the change of publicity investment, predict the number of tourists under different levels of publicity investment, and provide scientific basis for the government to formulate the publicity strategy.

2) Additional assumptions and justifications:

It is assumed that there exists an upper limit on the visitor capacity of cold spots K and that government investment in publicity (E_{i4}) can boost the growth of visitor numbers, but the growth rate will gradually slow down as the number of visitors approaches the capacity. In actual tourism scenarios, the carrying capacity of each attraction is limited, and when the number of tourists approaches or reaches the upper limit of the carrying capacity, it is difficult for the number of tourists to grow significantly even if the investment in publicity is increased.

3) Calculation

Let the number of tourists in cold spots be V_{cold} , the investment of government publicity be E_{i4} , and the expression of Logistic model be

$$\frac{dV_{cold}}{dt} = rV_{cold}\left(1 - \frac{V_{cold}}{K}\right) \times \frac{E_{i4}}{(E_{i4} + \xi_i)}$$

Where r is the intrinsic growth rate of visitor numbers, reflecting the rate of growth of visitor numbers when there are no resource constraints; K is the upper limit of visitor accommodation for the attraction; and ξ_i is a constant to indicate the sensitivity of the impact of promotional investment on the growth of visitor numbers. The equation reflects the contribution of promotional investment to the growth of visitor numbers and the change in the growth rate as the number of visitors approaches the upper capacity limit. By solving this differential equation, a functional relationship can be obtained between the number of touristsV_{cold} as a function of time t and promotional investment E_{i4} .

3.2.6 A study of specific tourist destinations:

Located on the southern limestone peninsula of the Dalmatian Coast in southern Croatia, Dubrovnik is Croatia's largest tourist center and health resort, and was inscribed on UNESCO's World Heritage List in 1979.

Historical and Architectural Attractions - Dubrovnik Old Town: Numerous medieval buildings have been preserved in Romanesque, Gothic, Renaissance and Baroque styles. There are famous buildings such as the 14th century pharmacy, St. Vlach church, Dominican Monastery, Dubrovnik Cathedral, Great Onofre Fountain and so on, which is one of the best preserved medieval architectural areas in Europe.

Natural landscape attractions - Banje Beach: one of the most beautiful beaches in Dubrovnik, with crystal clear water and golden sand, backed by the old castle and city walls and surrounded by ancient trees in a picturesque landscape.

Featured Small Town Attractions (Relatively Cold): The small town of Cavat, located near Dubrovnik, Croatia, is situated on the scenic Adriatic coastline and boasts a mild Mediterranean climate with four pleasant seasons, making it a charming seaside town.

1) Model migration application:

A) Historical and cultural attractions (using the Old Town of Dubrovnik as an example)

Maintenance of cultural and tourism venues: Most of the buildings in the Old City are masonry structures and are old, making them difficult to maintain. Therefore, the above maintenance cost item has been added.

$$Mcost_i = \gamma_i V_i + \delta_i F(V_i)$$

When calculating maintenance costs, γ_i and δ_i are determined by the structural stability of the building and the age index, Finding information about the city has Old Town buildings built in the 16th century.

When calculating the resident satisfaction index S_i, the old city has a large number of tourists and concentrated activities, which have a high impact on residents' lives. In the original model, the weight of the number of tourists V_i on residents' satisfaction w_{1ori} is adjusted to w_{1new} and $w_{1new} > w_{1ori}$. It is found that tourists interfere with residents' life significantly, because the space of the old city is small, the influx of tourists leads to traffic congestion, noise increase, etc., which significantly affects residents' satisfaction.

When calculating the infrastructure pressure index F_i, the infrastructure of the Old City was built long ago and has limited carrying capacity. The parameters γ_i and δ_i related to the number of tourists in the original model need to be adjusted and increased to accurately reflect the pressure on the infrastructure of the old city caused by the increase in the number of tourists.

B) Beach islands around Dubrovnik

Biodiversity Conservation Issues: Tourists visiting beaches and islands may have negative interactions with local wildlife, such as disturbing the normal spawning of marine animals, etc. The impact of tourists on organisms can be accurately reflected with the help of PIE, and the results can be corrected by adding environmental scores to the carbon emissions, τ is the constant related to the demand for conservation of the attraction.

$$PIE \approx \frac{2V_i N}{(V_i + N)^2}$$

$$C_i' = C_i - \tau PIE$$

Scenic seasonal popularity problem: Due to the local Mediterranean climate, summer is the peak season for beach attractions, assuming that the number of travelers in the peak season is k times the number of travelers in the off-season, and from the model above there is

$$F'(V_i) = \gamma_i V_i + \delta_i V_i^2 \times 2\frac{1 + k^2}{(1 + k)^2}$$

$$F'_i = F'(V_i)$$

Adjustments are made to the Infrastructure Stress Index, which also provides a more accurate reflection of changes in resident satisfaction.

Since there are fewer residents in the scenic area and it is mainly a natural landscape, the objective function for this scenic area can be calculated by reducing the proportion of resident satisfaction and increasing the proportion of environmental protection accordingly to better reflect sustainability.

C) Relatively neglected spots (take the town of Cavat in Dubrovnik for example)

Impact of government investment in publicity on the number of tourists (Logistic model): let the government invest $\mathbf{E_{i4}}$ in the area of publicity, which positively affects its number of tourists

$$\frac{dV_i}{dt} = rV_i\left(1 - \frac{V_i}{K}\right) \times \frac{E_{i4}}{(E_{i4} + \xi_i)}$$

The number of tourists is more sensitive to promotional funding due to popular attractions such as the nearby ancient city.ξ_i smaller, the promotion has a greater impact on local tourism.

In the calculation of the resident satisfaction index S_i of Cavat Town, the number of tourists has a large impact on resident satisfaction. The weight of the influence of the number of touristsV_i on the satisfaction of residentsw_{1ori} in the original model needs to be increased significantly, while the environmental index can be reduced appropriately.

3.2.7 Overall Objective Function

Let the three attractions of Dubrovnik Old Town, Banje Beach, and Cavat Town be Attraction 1, Attraction 2, and Attraction 3, respectively, whose corresponding overall profit indices areP_1 ,P_2 , andP_3 , with weightsw_{total1} ,w_{total2} , andw_{total3} , respectively, and

$$w_{total1} + w_{total2} + w_{total3} = 1$$

Over a period of time, let the number of visitors to Attraction 1 beV_1 , the number of visitors to Attraction 2 beV_2 , the initial number of visitors to Attraction 3 be$V_{3\text{初}}$, and the number of visitors added due to publicity beΔV_3 (as determined by the logistic model) and satisfy

$$V_1 + V_2 + \left(V_{3origin} + \Delta V_3\right) = C$$

(C is a constant, indicating that the sum of the three attractions is constant). Then the total objective function$Z$ is:

$$Z = w_{total1} \times P_1 + w_{total2} \times P_2 + w_{total3} \times P_3$$

Among them,P_1 ,P_2 andP_3 are calculated according to the characteristics of their respective attractions and the corresponding formulas, the ratio of the number of touristsV_1 andV_2 inP_1 andP_2 remains unchanged, and the number of tourists inP_3 is$V_{3origin} + \Delta V_3$.

3.2.8 Recommended policies

1. Cultural heritage protection policy: For the old town of Dubrovnik, in view of the difficulty of maintaining its buildings, the Government should set up special funds for cultural heritage protection. The sources of funds may include a part of tourism tax, governmental financial allocations and social donations. Utilizing this fund, a comprehensive

inspection and restoration of the buildings in the old town should be carried out on a regular basis, and maintenance resources should be rationally arranged according to the structural stability and age index of the buildings. At the same time, strict regulations on tourist visits, such as limiting the number of tourists entering each day and specifying the routes to be taken, should be formulated to minimize the damage caused to the buildings by tourists' activities and to ensure that the cultural heritage is properly protected.

2. Biodiversity conservation policy: In the area of the beach islands around Dubrovnik, the Government needs to strengthen the regulation of tourist activities. Specialized ecological protection zones should be set up to prohibit tourists from entering some sensitive wildlife habitats, especially during critical periods such as animal breeding and spawning. Increase publicity on marine biodiversity protection, raise tourists' awareness of environmental protection, and guide them to visit the area in a civilized manner by setting up publicity slogans in scenic spots and carrying out environmental education activities. In addition, in cooperation with scientific research institutions, the biodiversity of the region is regularly monitored, and the protection strategy is promptly adjusted according to the monitoring results.

3. Tourism seasonal regulation policy: Based on the obvious difference in seasonal heat of Dubrovnik scenic spots, the government should comprehensively apply a variety of regulation means. In terms of publicity, increase the promotion of off-season tourism, and develop special tourism promotion programs for different seasons. For example, tourism activities related to local cultural festivals should be launched in winter to attract tourists to go there in the off-season. In terms of price regulation, implement off-season preferential policies and offer discounts on scenic spot tickets, hotel accommodation, transportation and other expenses. At the same time, rational planning and construction of infrastructure should be carried out to improve the carrying capacity of infrastructure during the peak season, such as increasing the frequency of public transportation and building temporary parking lots to ease the pressure on infrastructure during the peak season.

4. Support policy for cold spots: For cold spots like Cavite Town, the government should increase its investment in publicity. According to the Logistic model, accurately formulate the publicity strategy and determine a reasonable scale of publicity investment. Strengthen the cooperation with the surrounding popular attractions, launch joint tourism routes, leverage the flow of popular attractions to drive the development of Cavat Town, and alleviate the pressure of tourists from the surrounding popular attractions. In terms of the town's infrastructure construction, increase investment to improve the conditions of transportation, lodging and catering, and increase the capacity to receive tourists. In addition, local residents are encouraged to participate in tourism business activities and are given certain policy support and training to promote local economic development.

5. Comprehensive regulation and assessment policy: Establishment of a unified tourism regulatory body to regulate all aspects of Dubrovnik's attractions. Formulate comprehensive standards and norms for the tourism industry, covering a wide range of aspects such as the environment, cultural heritage protection, service quality, etc., and impose severe penalties on tourism enterprises and individuals who violate the rules. Regularly assess the development

of tourism and analyze the sustainability of tourism development based on the general objective function and various monitoring indicators. Based on the results of the assessments, tourism policies and development strategies are adjusted in a timely manner to ensure the long-term and stable development of the tourism industry.

4 Model Evaluation

4.1 Strengths

Strength 1: Comprehensive consideration of multiple factors in sustainable tourism：Our model takes into account various aspects of sustainable tourism, including tourism revenue, environmental protection, infrastructure load, and local satisfaction. It comprehensively evaluates the complex relationships between these factors, which is more in line with the real - world situation of tourism development. For example, in calculating tourism revenue, we consider the direct spending of tourists, and in environmental protection, we use multiple indicators such as carbon footprint and pollution index. This holistic approach helps to better understand the overall impact of tourism on a destination.

Strength 2: High adaptability to different destinations： The model can be flexibly adjusted according to the characteristics of different tourist destinations. When applied to destinations like Dubrovnik, we can incorporate specific factors such as cultural heritage maintenance and seasonal tourism impacts. By adjusting parameters and adding relevant variables, the model can accurately reflect the unique situations of different places, providing targeted solutions for sustainable tourism development in various regions.

Strength 3: Incorporation of dynamic and interactive relationships： The model reflects the dynamic and interactive relationships between different sections. The variables in tourism revenue, environmental protection, and infrastructure load sections interact with each other. For instance, changes in the number of tourists will affect tourism revenue, carbon emissions, and infrastructure load simultaneously. This dynamic interaction can better simulate the real - time changes in the tourism system and help decision - makers understand the complex consequences of different policies.

4.2 Weaknesses

Weakness 1: Simplification of complex real - world situations： Although the model attempts to comprehensively consider various factors, it still simplifies some complex real - world situations. For example, in reality, the relationship between tourism development and local economic structure is more complex than assumed in the model. There may be many hidden economic links and feedback mechanisms that are not fully considered in the model, resulting in an incomplete reflection of the real - world situation.

Weakness 2: Lack of consideration of some random and extreme events：The model does not fully consider the impact of random and extreme events. Natural disasters, global health crises, and sudden changes in international relations can all have a huge impact on tourism. For example, the COVID - 19 pandemic has severely hit the tourism industry, but this kind of extreme event is not included in the model, which may limit the model's ability to respond to emergencies.

5 Conclusion

To develop a sustainable tourism model for Juneau and other destinations, we constructed a comprehensive model considering multiple aspects such as tourism revenue, environmental protection, infrastructure load, and local satisfaction. We collected relevant data from various sources like local surveys and industry reports. For different types of destinations, we adjusted the model by incorporating specific factors like pollution levels, cultural heritage maintenance costs, and seasonal tourism impacts.

For other destinations, like Dubrovnik, specific adjustments such as considering cultural heritage maintenance and seasonal tourism characteristics are crucial. The optimal strategies vary according to different destinations' features. For popular historical sites, strict protection and reasonable tourist flow control are essential; for beach destinations, environmental protection and sustainable tourism development are key; and for less - visited areas, promotion and infrastructure improvement are priorities.

Based on our analysis, we gave advice on policies for optimizing outcomes. We suggested an optimal volume of tourists which brings the biggest overall profit. Also, through calculation, we proposed the optimal proportion of investment in three aspects: infrastructure, community services, and environmental protection, in order to make the tourism more sustainable.

Future research could relax some of the assumptions in our model. For example, we could consider more complex relationships between tourism and the economy, such as the long - term impact of tourism on local economic structure. Also, we could account for the impact of unexpected events like natural disasters or global health crises on tourism. In general, promoting sustainable tourism requires cooperation among the government, tourism industry, and local communities. More emphasis should be placed on building a collaborative management mechanism to balance economic development, environmental protection, and local well-being.

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