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Research on Sustainable Tourism Development based on Multi-Objective Planning Models

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Abstract

This paper focuses on sustainable tourism development, takes Juneau as the research object, constructs relevant models and carries out in-depth analyses. We collect data on the number of tourists, tourism revenue and carbon emissions in Juneau from 2009 to 2023, clarify the trend of each factor through data visualisation, and analyse the relationship between tourism tax, the number of tourists and maintenance costs. Two objective functions are set up to maximise the net profit of tourism and minimise the carbon emission, in which the net profit involves the calculation of total revenue and total cost, and the total cost is related to the number of tourists, tourism tax and other factors; the carbon emission is affected by the number of tourists and the maintenance cost, and the correlation coefficients are solved by fitting the data. A multi-objective planning model is constructed and then converted into a single-objective optimisation model to simplify the solution, determine the upper limit of carbon emissions, and then obtain the optimal solution. The model is applied to Lijiang Old Town in China, and after data calculation, model optimisation, and visual comparison of the results before and after optimisation, it is found that reasonable adjustment of the tax rate and optimisation strategy can enhance the net income and balance the number of tourists and environmental impacts. The research results provide an important reference for tourism policy making and help promote the sustainable development of tourism.

Keywords

Sustainable Tourism; Juno; Multi-objective Planning Model; Lijiang Old Town; Tourism Policy.

1. Introduction

Against the backdrop of global economic prosperity, tourism has flourished and become an important driving force for the economic growth of many cities, playing a significant role in creating employment, spreading culture and shaping the image of cities. However, at the same time, the rapid development of tourism has brought about environmental pressure, excessive consumption of resources and other issues are becoming increasingly prominent, how to achieve sustainable development of tourism has become a key issue [1].

Juno, as a tourist destination, is facing the challenges of carbon emission increase and infrastructure maintenance while the number of tourists and tourism revenue are increasing. Constructing a sustainable tourism model is of great significance in solving the current dilemma and exploring the long-term development path. Lijiang Ancient City also faces the dual challenges of tourism development and environmental protection. Applying Juno's model to Lijiang Ancient City can optimise the model and provide a development strategy, which is of great significance to the development of global tourism cities, and is conducive to the coordinated development of the tourism industry in terms of economy, society and environment [2].

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2. Modelling Sustainable Tourism for Juneau

We collected data on tourist numbers, tourism revenue, carbon emissions, and other relevant factors in Juneau from 2009-2023. Through data visualization, we found that tourist numbers and revenue showed an increasing trend over the years, while carbon emissions also increased with the growth of tourist numbers. Additionally, the relationship between tourist tax, tourist numbers, and maintenance costs was analyzed, providing a basis for model establishment [3].

2.1. Objective Functions

Maximization of Tourism Net Profit:

Net profit (NP) is calculated as total revenue minus total cost. Total revenue ($R(x)$) is assumed to be proportional to the number of tourists, and total cost[$\mathrm{C(x,t,N)}$] is related to tourist numbers, tourist tax, and other factors. Here we simplify the model, assuming that the total income is proportional to the number of tourists, and the total cost is related to the number of tourists, tourism tax and the upper limit of tourists (for example, infrastructure improvement and environmental protection supported by taxes). The formula of objective function 1 is as follows:

$$NP = R(x) - C(x,t,N) \tag{1}$$

$$R(x) = p \cdot x \tag{2}$$

$$C(x,t,N) = c1x + c2 \cdot xt + c4 \tag{3}$$

To solve c1 and c2, we get the data of Juneau from 2009 to 2023 to fit the function, as shown in figure 1 below.

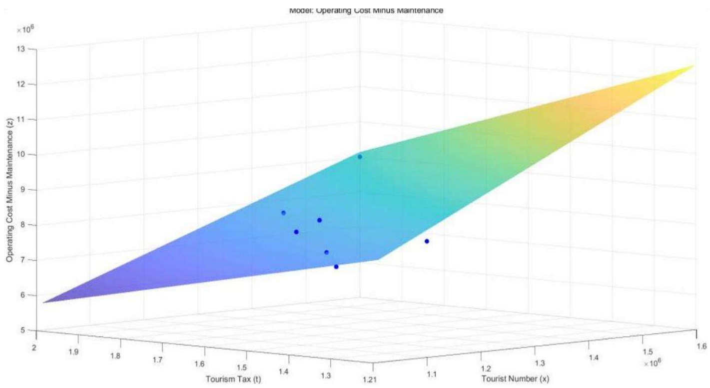

Figure 1. the model of operating cost minus maintenance

In the above figure, the X -axis represents the number of tourists X, the Y -axis represents the tourism tax T, the Z -axis represents the net operating expenditure of tourism, and the blue dot represents the original data point, reflecting the operating cost minus the maintenance cost under different tourist numbers and tax levels. The color surface is based on the fitting result of the formula, showing the forecast trend of Z. The results show that the number of tourists and tax have a significant positive impact on the net operating expenditure. More tourists and higher tax levels have jointly promoted the growth of operating expenses. Policymakers should reasonably balance the tax policy and the expansion of the number of tourists to support the sustainable development of tourism.

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Assuming that a certain proportion of tourism tax revenue and government basic expenditure revenue is used for tourism sustainable development and maintenance, there are the following constraints $c_4 = k_1 \cdot x \cdot t$ Here, the proportion of tax revenue used to improve the environment and make tourism sustainable development can be adjusted in a proper range according to the actual situation. We use the data of Juneau from 2009 to 2023 to fit the constraints and calculate the coefficients, as shown in figure 2:

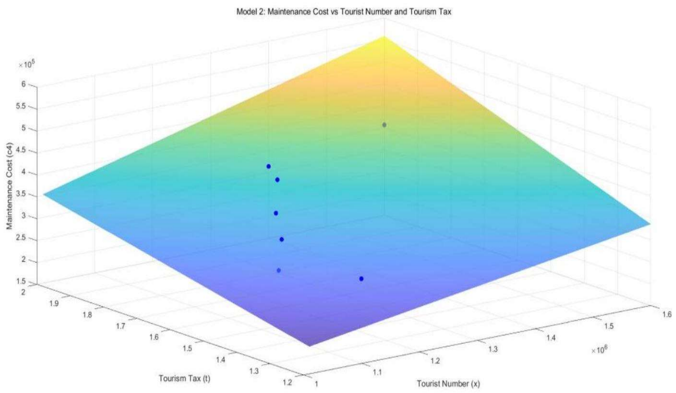

Figure 2. maintenance cost vs tourist number and tourism tax

In the above figure, the X -axis represents the number of tourists X, the Y -axis represents the tourist tax T, and the Z -axis represents the maintenance cost. The blue scattered points are the original observation data points, representing the actual maintenance cost under different tourist numbers and tax levels. The colored curved surface is the fitting result based on the model formula(4), which is used to show how the maintenance cost changes with the number of tourists and tax levels.

The fitting results show that the maintenance cost has a linear positive correlation with the number of tourists and tax. The increase in the number of tourists will significantly push up the maintenance cost, and the increase in tourism tax will provide the necessary financial support for maintenance. This discovery shows that it is of great significance to formulate a reasonable tax policy to support the sustainable development of tourism.

The increase of tourists' satisfaction with infrastructure maintenance and environmental protection will promote the increase of tourists. Considering the limitations of environment and resources, it will hinder the growth of tourists, and the blocking effect will become greater and greater when the number of tourists increases to a certain extent. The improvement will help the increase of tourists, but the marginal benefit will be obtained. Then the following logistic model is obtained:

$$x(c_4) = \frac{x_m}{1+\left(\frac{x_m}{x_0}-1\right)e^{-rc^4}} \tag{4}$$

Tourist tax has a certain inhibitory effect on the number of tourists.

$$x(t) = \frac{k_2 \cdot x_m}{t} \tag{5}$$

Considering (5) and (6) comprehensively, formula (7) can be deduced:

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$$x = w_1 \frac{x_m}{1+\left(\frac{x_m}{x_0}-1\right)} + w_2 \frac{k_2 \cdot x_m}{t} \tag{6}$$

w_1, w_2 is the combination factor, in which the parameters $x_m, x_0, r, k_2, w_1, w_2$ can be estimated by least square fitting.

We calculate the correlation coefficient by fitting the logistic model to the data of Juneau from 2009 to 2023, and the coefficient reflects the comprehensive influence relationship between maintenance cost and tourism tax on the number of tourists, as shown in figure 3:

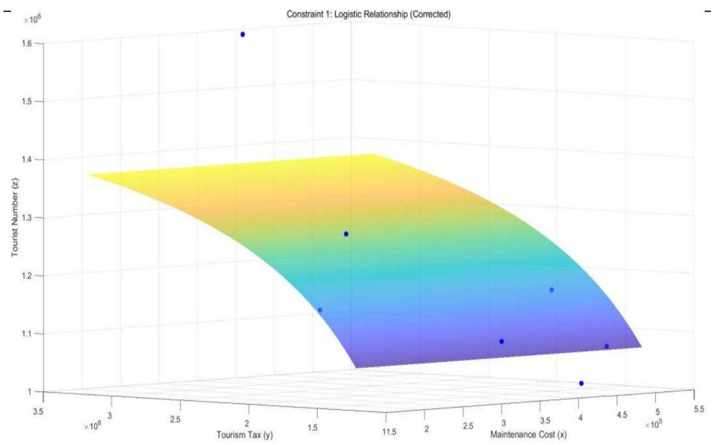

Figure 3. logistic relationship

The X-axis in the above figure represents maintenance cost, the Y-axis represents tourism tax, the Z-axis represents the number of tourists, and the blue dots are the original data points, indicating the number of tourists actually observed under different combinations of maintenance cost and tourism tax. Color surface is a relation curve obtained by fitting Logistic model. From the trend of the surface in the figure, it can be concluded that the maintenance cost X has a slightly positive impact on the number of tourists, and the surface rises with the increase of X ; The tourist tax Y also has a positive impact on the number of tourists, and the curve increases with the increase of Y, which may reflect an implicit mechanism: high taxes may be related to high-quality services or better maintenance, thus attracting more tourists, and tourists are willing to pay higher taxes to get a better travel experience. At the same time, the increase in the number of tourists will naturally increase the total tax revenue.

The annual optimal profit can be calculated by increasing the carbon emission ceiling standard from 30000 to 37000 in turn, and the number of tourists is shown in the following table 1.

Table 1. The relationship among three variants

2517102	Parism profit	Page 12
Carbon emission	164325356	Tourism number
30000	170158099	726476
31000	176110421	752340
32000	182243820	878760
33000	188680851	806021
35000	195733768	834691
36000	205058440	968220

From the calculation results, the increase of carbon emissions can bring about an increase in the number of tourists and tourism profits to a certain extent, but the growth rate is not very large. Therefore, if we excessively pursue profits and neglect environmental protection, it may bring shortterm benefits without taking advantage of the long-term sustainable development of tourism.

Minimization of Carbon Emissions:

In order to solve the coefficient e and α, we use the data of Juneau from 2009 to 2023 to fit the objective function, as shown in figure 4.

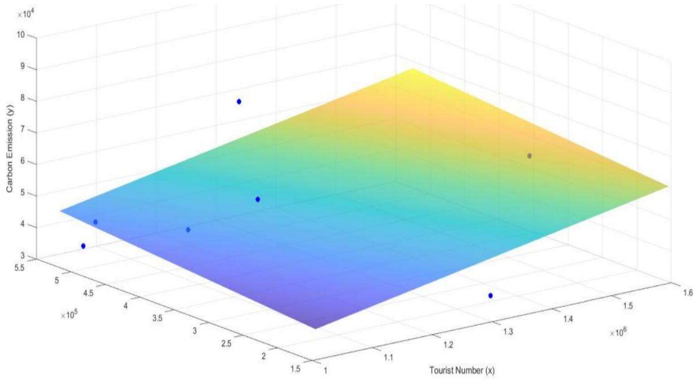

Figure 4. Carbon emission model

In the above figure, the X -axis represents the number of tourists, the Y -axis represents the maintenance cost, the Z -axis represents the total carbon emission of tourism activities and related facilities, and these blue dots represent the original observation data points, reflecting the actual carbon emission values under different combinations of tourists and maintenance costs. The color surface is drawn based on the fitting model. It shows the comprehensive influence trend of maintenance cost and the number of tourists on carbon emissions.

As can be seen from the figure, carbon emissions show an increasing trend with the increase of the number of tourists, while the increase of maintenance cost shows the effect of restraining carbon emissions. It can be seen that the environmental pressure caused by the increase in the number of tourists can be offset to some extent by increasing the maintenance cost.

Formula (10) constrains the maximum number of tourists because traffic congestion is related to the number of tourists, limiting the number of tourists can alleviate traffic pressure.

In 2023, Juneau received 1.6 million passengers, and the total tourism revenue was about 375 million US dollars. According to this calculation, the average consumption per tourist is about \$234.

2.2. Multi-objective Programming Model

Objective function:

$$\begin{cases} \max[p \cdot x - c_1 \cdot x - c_2 \cdot x \cdot t - c_4] \\ \min(e \cdot x - \alpha \cdot c_4) \end{cases} \tag{7}$$

$$\text{s.t.} \begin{cases} x = w_1 \frac{x_m}{1+\left(\frac{x_m}{x_0}-1\right)e^{-rc_4}} + w_2 \frac{k_2 \cdot x_m}{t} \\ c_4 = k_1 \cdot x \cdot t \end{cases} \tag{8}$$

Because the pursuit of maximizing tourism profits and protecting the environment restrict the sustainable development of tourism, in order to simplify the solution of the model, the multiobjective programming model is transformed into a single-objective programming model.

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For the sustainable development of tourism, determine the upper limit of carbon emissions B, that is, carbon emissions within the limit B can maintain the sustainability of tourism revenue, and optimize tourism revenue on this basis [4], and the following single-objective optimization model can be obtained:

The upper limit of carbon emission b has not been completely determined, and it should exist in a certain reasonable range. When solving it, it can be set in a certain range to circularly search for the optimal solution of different b values and find the effective frontier. In other words, taking b = 35735 for sensitivity analysis and the lowest carbon emission value in the table data, we can calculate the optimal annual profit of 2.0200e + 08, which is $202 million, with 894410 tourists and $155430 for the sustainable development of tourism.

3. Modelling Applications and Scenic Promotion

We apply the model to Lijiang Old Town in Lijiang City, Zhejiang Province, China. Firstly, relevant data are collected and the relationship between the number of tourists, tourism tax and carbon emission in Lijiang Old Town of Lijiang City, Lijiang City, China, is analysed based on the model; then the optimisation algorithm above is used to optimise the balance between tourism and environmental protection, and finally the results before and after the optimisation are visualised and compared [5].

The constraints on the objective function of the multi-objective planning model are the same as in Section I. First, we calculate the coefficients in the planning model from the data.

After the solution, we optimize the model, and the results are shown in the following table 2:

Table 2. Optimized solution results.

Feature	Result
Number of tourists x	29728000
Tax level t	0.41 ∗ Basic tax rate
Maintenance cost C_4	841740
Maximum net -income Q	45172000000

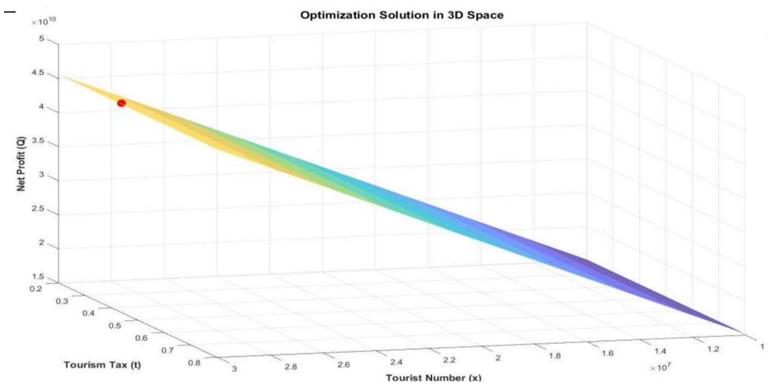

Figure 5. Optimisation Analysis of Tourism Tax and Visitor Numbers on Net Revenue

The colored curved surface in the figure 5 shows the changing trend of net income Q under different tax rates T and tourists number X. The color gradient clearly reflects the distribution law of net income, and the influence of different combinations of tax rate and number of tourists on net income is obvious. The surface shows a certain slope change, which shows that the net income decreases significantly when the tax rate is low or the number of tourists is small. The red marked points indicate the optimal solution obtained by the optimization model under the given constraints. It can be observed from the figure that when the number of tourists increases to a certain range, the increase of tax rate will have a significant negative impact on the net

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income, which shows that it is necessary to balance the relationship between tourist flow and tax rate in actual decision-making. The tax rate T of the point optimization solution is in the middle level, which is consistent with the actual data trend, which proves the rationality and applicability of the optimization model.

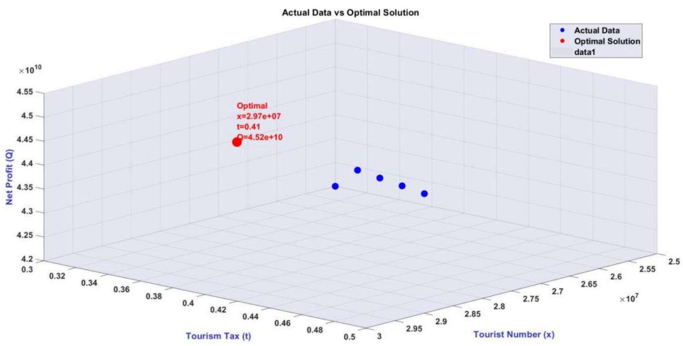

Figure 6. comparison diagram of actual data and optimized solution

This figure 6 compares the difference between the actual observation data and the optimal solution obtained by the optimization model. The blue dots represent the tourism tax, the number of tourists and the corresponding net income calculated based on historical data, reflecting the distribution trend in the actual system. The red dot represents the optimal solution calculated by the optimization model under the constraint conditions. The diagram clearly shows the comparison between the actual observation value and the optimized solution of the model, which provides an intuitive reference for the formulation of tourism policies. The research results show that reasonable tax rate adjustment and optimization strategy can effectively improve the net income, balance the number of tourists and environmental impact, and find a more suitable matching point among the number of tourists, tax revenue and income.

4. Conclusion

Focusing on the sustainable development of tourism, this study constructs the Juno tourism model and applies it to Lijiang Ancient City with remarkable results. By analysing the data of Juno from 2009 to 2023, the study clarifies the relationship between the key factors, and the objective function and optimisation model established provide strong support for the formulation of Juno tourism policy. The application of the model in Lijiang Ancient City successfully verifies its validity and universality, achieving a balance between tourism and environmental protection, and providing a practical reference for Lijiang and similar tourist places. The results of this research provide new ideas for the coordination of economy, environment and resource utilisation in tourism cities, and are of great value in promoting the sustainable development of global tourism.

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