Tourism Development Study of Juno ICSS Model Based on Multi-Objective Genetic Algorithm NSGA-II

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Abstract. This paper focuses on sustainable tourism and constructs an ICSS model based on the multi-objective genetic algorithm NSGA-II for Juneau, aiming at solving the multi-objective optimization problem and determining the optimal number of tourists per day, which can provide a basis for policy formulation. The objective function of the model takes into account the total local income, the implicit cost of environmental protection policy and the satisfaction of residents, and sets the constraints of the number of tourists, implicit cost and the satisfaction of residents at the same time. The relationship between the variables is determined by establishing sub-models of income, hidden costs and residents' satisfaction. After parameterization and simulation, it is concluded that the sustainable tourism evaluation index Z is maximized when the number of daily tourists in Juneau reaches 9,500. The model can be migrated to other cities affected by over-tourism, such as Honolulu, where the optimal number of visitors is 13,200 after re-fitting the parameters. In addition, considering the situation of multiple attractions in the city, the SST model is improved to optimize the evaluation indexes, balance the number of tourists in the attractions, and improve the utilization rate of resources, which provides a reference for tourism planning.

Keywords: Sustainable tourism; multi-objective genetic algorithm; model construction; model migration and generalization.

1. Introduction

With the rapid development of global tourism, over-tourism has brought problems to many destinations in terms of environment, infrastructure and residents' life, and sustainable tourism development has become a key issue. Juneau faces the challenge of balancing economy, environment and residents' satisfaction while pursuing tourism revenue, which is a typical multi-objective optimization problem.

Although existing tourism research involves economic and environmental aspects, there are fewer studies that consider multiple factors comprehensively to construct a sustainable development model.

To this end, this paper constructs an ICSS model based on the multi-objective genetic algorithm NSGA-II to determine the optimal number of daily tourists in Juneau. The model is applied to other similar cities to further optimize the model to adapt to the city's multiple attractions and provide an effective solution for the sustainable development of tourism.

2. The basic model of sustainable tourism based on Juneau

2.1. Model building

Juneau hopes to get more tourism revenue, maintain sustainable tourism development and ensure residents' satisfaction and environmental protection, which is a typical multi-objective optimization problem. Based on the multi-objective genetic algorithm NSGA-II, we establish an the ICSS Model. This model can solve the optimal number of visitors per day in Juneau, and provide a basis for policy making.

2.1.1. Objective function

Taking the local total income, the hidden costs generated by environmental protection policies and the residents' satisfaction as our optimization objectives, finally, we get the objective function of the optimization model as follows:

$$maxZ = w_1 \cdot \frac{L^\alpha}{L_{max}} - w_2 \cdot \frac{Y(P)^\beta}{Y_{max}} + w_3 \cdot \frac{F(P)^\gamma}{F_{min}} \tag{1}$$

Where Z is the evaluation index of sustainable tourism, which is used to evaluate the quality of local tourism development, P is the number of tourists received every day. w_1, w_2 and w_3 are the weight coefficients of total income, hidden cost and residents' satisfaction to the objective function, respectively, and should satisfy the weight relationship of $w_1 + w_2 + w_3 = 1$. α, β and γ are the weight indexes of total income, hidden cost and residents' satisfaction to the objective function respectively. L Is the total income, $Y(P)$ brings hidden costs to Juneau when tourists travel, including drinking water supply, waste management, carbon footprint increase, etc. $F(P)$ is the satisfaction of residents, including housing supply and cost, overcrowding and noise, employment opportunities due to the increase of tourists.

2.1.2. Constraint condition

The number of tourists in Juneau cannot be negative, so $P \geq 0$. For the sake of safety and the carrying capacity of infrastructure, the number of daily visitors in Juneau cannot be infinite. Combined with the above conditions, we get the constraint condition of the number of visitors per day P.

$$0 \leq P \leq P_{max} \tag{2}$$

To ensure the smooth travel of tourists every day, the government needs to increase the frequency of infrastructure maintenance, and at the same time, the daily garbage to be treated increases rapidly with the arrival of tourists, which undoubtedly increases the burden on the local government. Of course, if the hidden cost is too high, the government can't make ends meet. Therefore, we restrict the hidden cost not to be higher than a certain threshold:

$$Y(P) \leq Y_{limit} \tag{3}$$

In addition, the constraint of residents' satisfaction should also be taken into consideration. The environmental damage, overcrowding and noise caused by tourism will lead to residents' dissatisfaction with tourism. Therefore, we should find a minimum tolerance limit for residents to tourism:

$$F(P) \geq F_{min} \tag{4}$$

2.1.3. Establishment of sub-models

Model 1: Income model

The total income has a linear relationship with the number of tourists received every day and the per capita consumption of tourists [1]. Therefore, we define it as:

$$L = P \cdot M \tag{5}$$

Among them, L is the total income, P is the number of tourists received every day, and M is the per capita consumption of tourists.

Model 2: Hidden cost model

Here, we simplify the model as the hidden cost is only affected by three factors: drinking water supply, waste management and increased carbon emissions. Usually, these hidden costs will increase with the increase of tourists, but the speed of increase will be different due to various factors such as management efficiency, technological progress, policy intervention and so on [2].

To construct the mathematical function relationship between the number of tourists P and the hidden cost $Y(P)$, we need to consider the changing trend of these three factors with the number of tourists respectively.

1. The relationship between carbon emissions and tourists

Carbon emissions are not only related to the number of tourists, but also influenced by tourists' behaviors, modes of transportation, seasonal changes and other factors. To simplify the calculation, we assume that the relationship between carbon emissions and the number of tourists is a simple quadratic function. Therefore, we design the relationship between carbon emission $Y_{carben}(P)$ and the number of tourists as follows:

$$Y_{carben}(P) = a_1 \cdot P + b_1 \cdot P^2 + Y_1 \tag{6}$$

2. The relationship between drinking water supply and tourists

The data show that there is a nonlinear relationship between water consumption and the number of tourists [3]. Because with the increase in the number of tourists, drinking water supply facilities cannot linearly expand with the number of tourists. Therefore, water consumption will accelerate with the increase of tourists. Water consumption $Y_{water}(P)$ is defined as:

$$Y_{water}(P) = a_2 \cdot log(P+1) + b_2 \cdot P + Y_2 \tag{7}$$

3. The relationship between waste management and tourists

There is no doubt that the cost of basic garbage recycling increases with the increase of the number of tourists, and this growth increases in the form of a power function with the increase of the number of tourists, especially when the number of tourists approaches the maximum carrying capacity of the scenic spot, its cost will increase significantly [4]. Therefore, we define the relationship between the waste management cost $Y_{infra}(P)$ and the number of tourists as follows:

$$Y_{infra}(P) = a_3 \cdot P^{\varepsilon} + Y_3 \tag{8}$$

4. Combine the above three hidden cost models to get the total hidden cost $Y(P)$

$$Y(P) = Y_{carben}(P) + Y_{water}(P) + Y_{infra}(P) \tag{9}$$

Model 3: Resident satisfaction model

In this model, we should not only consider the positive impact between residents' satisfaction and the increase of employment opportunities and income, but also consider the negative impact between residents' satisfaction and the rise of housing prices and overcrowding. We take the average satisfaction of residents when there are no tourists as the starting point, taking the positive and negative effects into consideration, and comprehensively adjust the relationship between residents' satisfaction and the number of tourists. Therefore, the residents' satisfaction F can be obtained as follows:

$$F = F_0 + a_4 \cdot P^{\theta} - b_4 \cdot P^{\zeta} \tag{10}$$

Among them, F_0 is the basic satisfaction, that is, residents' inherent satisfaction with local life when there are no tourists? P Is the number of tourists received every day? a_4 Is a positive influence coefficient, which indicates the degree to which the positive effect brought by the increase in the number of tourists will improve the satisfaction of residents? b_4 Is the negative influence coefficient, which indicates the degree to which the negative effect brought by the increase in the number of tourists reduces the satisfaction of residents?

In this formula, $\theta < \zeta$ must be satisfied [5], because we find that the positive impact will increase rapidly when there are few tourists, and its influence degree far exceeds the negative impact from the collected data. With the increase of tourists, its growth rate will gradually slow down and eventually be surpassed by the negative impact. The relationship between them is shown in Figure 1.

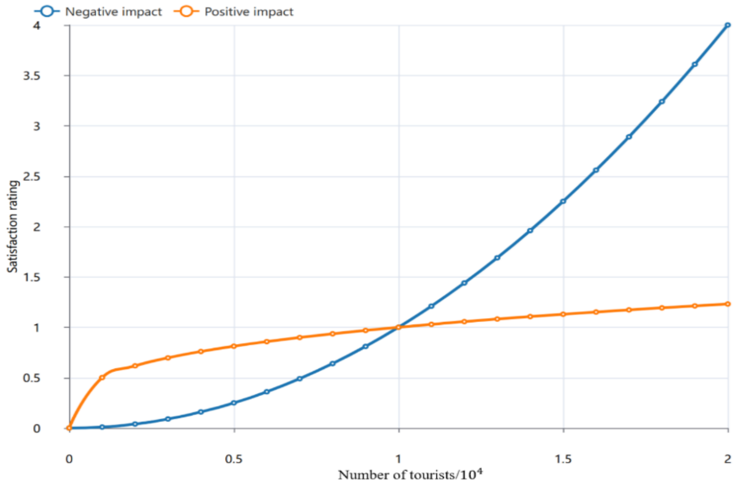

Fig 1. Relationship between positive and negative effects.

2.2. Solution of the model

2.2.1. Parameter setting

We fit the parameters of the basic model of sustainable tourism, and make appropriate adjustments in the process of genetic variation [6] to make the data get the best value in a suitable range. The final parameter values are shown in Table 1.

Table 1. Parameter Settings.

Parmeter	Value	Parmeter	Value	Parmeter	Value
α	1	F_{min}	20	b_3	0.05
β	2.3	M	234.38	b_4	0.0003
γ	2	a_1	0.5	Y_1	20.0
w_1	0.4	a_2	0.8	Y_2	10.0
w_2	0.3	a_3	0.2	F_0	50
w_3	0.3	a_4	0.6	ε	0.4
L_{max}	16000	b_1	0.15	θ	0.8
Y_{limit}	600000	b_2	0.12	ζ	1.2

2.2.2. Analog result

According to the data survey, we estimate that the maximum daily tourist carrying capacity of Juneau is 16,000. Therefore, we set the daily number of tourists P from 0 to 15,999, and simulate the change value of the evaluation index of sustainable tourism when the number of tourists increases gradually. The result is shown in Figure 2.

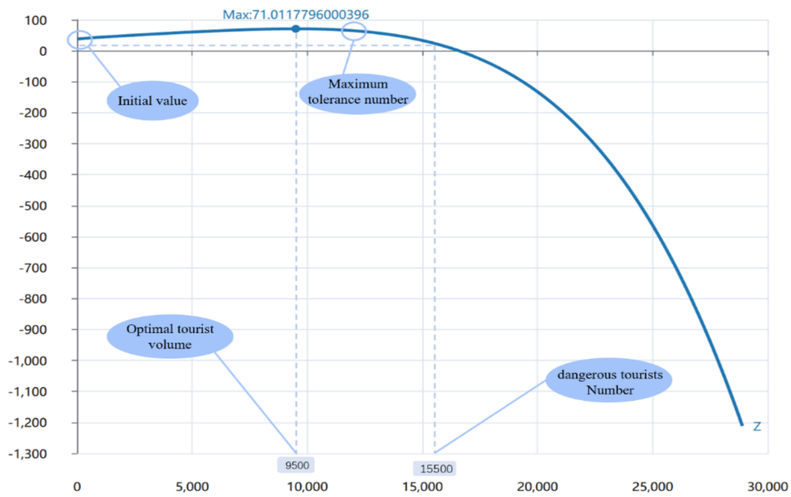

Fig 2. Analog result.

It can be concluded that with the increase of the number of tourists received every day, the evaluation index of sustainable tourism first rises and then falls. When the number of tourists reaches 9500, the evaluation index Z reaches the maximum value. We define the evaluation index value when the number of tourists is zero as the initial value, and the number of tourists when the evaluation index is the maximum as the best number of tourists.

3. Transfer and generalization of the model

3.1. Migration of the model to other tourism destinations affected by excessive tourism

From a global perspective, Juneau is not the only city affected by excessive tourism. Our model is also applicable to these cities. But different cities have different natural resources and government management, and their model parameters are also different. Taking Honolulu as an example, we will migrate the model.

Honolulu has a more developed economy, more complete government facilities, and higher income and employment levels for residents compared to Juneau. But it emits more carbon and incurs higher waste management costs. According to the data from the Data Network website, we refit the parameters and obtain new hyperparameters through genetic variation, as shown in the Table 2 below and the simulation results are shown in Figure 3.

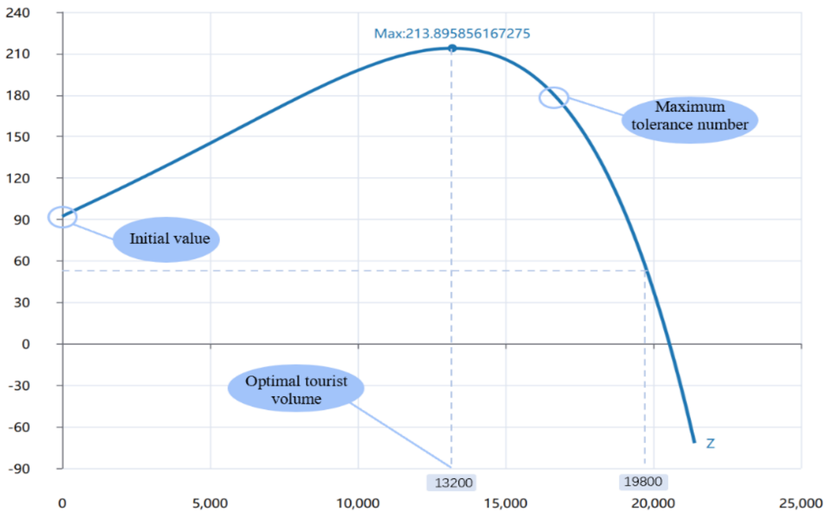

Fig 3. Evaluation Indicators for Sustainable Tourism Industry in Honolulu.

Table 2. Parameter Settings in Honolulu.

Parmeter	Value	Parmeter	Value	Parmeter	Value
α	1	F_{min}	50	b_3	0.05
β	2.7	M	246.33	b_4	0.02
γ	2.2	a_1	1.6	Y_1	60.0
w_1	0.4	a_2	0.6	Y_2	40.0
w_2	0.3	a_3	0.76	F_0	80
w_3	0.3	a_4	0.86	ε	0.08
L_{max}	12000	b_1	0.37	θ	0.96
Y_{limit}	4800000	b_2	0.12	ζ	1.003

It can be seen that the best number of tourists is 13200, the maximum tolerated number of tourists is 16500, and the dangerous tourist’s number is 19800, which is stronger than the tourist carrying capacity of Juneau.

3.2. Generalization of the Model

In the previous model, we simulated the city. However, a city will inevitably include multiple attractions, some with more people and others with fewer people. To solve the problem of excessive tourism, it is necessary to balance the number of tourists to the attractions. To this end, we further improve the model by considering cities as a combination of four typical scenic spots based on their capacity to accommodate tourists and residents' tolerance for tourists. We optimize the evaluation indicators for sustainable tourism and obtain SST Model. This model can be extended to various scenic spots, attracting tourists to visit and play in less crowded areas, making full use of tourism resources. The generalization idea of its model is shown in Figure 4.

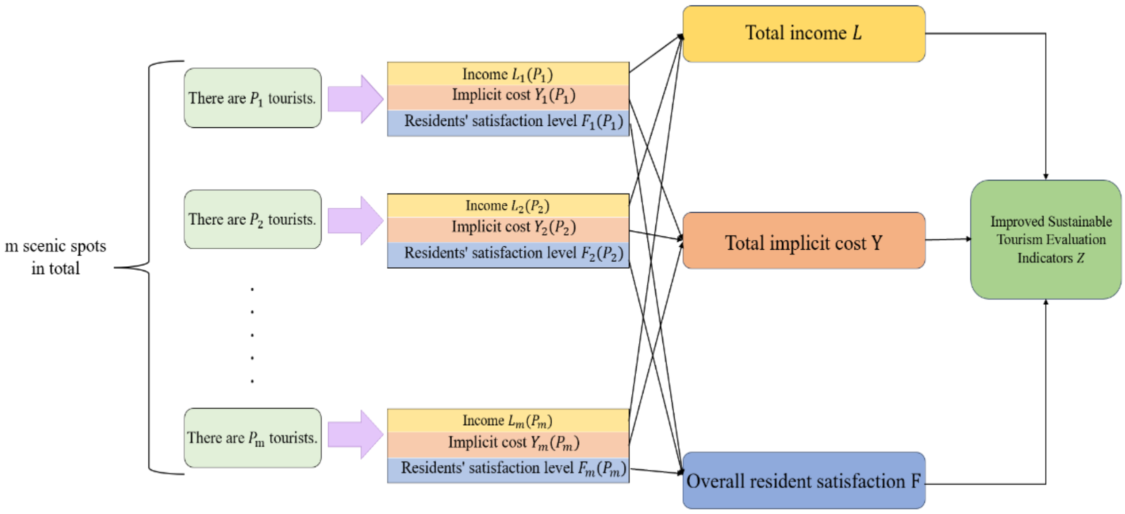

Fig 4. Strengthened Sustainable Tourism Model.

3.2.1. Objective Function and Constraints

The objective function of this optimization model is:

$$maxZ = w_1 \cdot \frac{L}{L_{max}} - w_2 \cdot \frac{Y}{Y_{max}} + w_3 \cdot \frac{F}{F_{min}} \tag{11}$$

Where w_1 , w_2 w_3 are weight coefficients, and they should satisfy $w_1 + w_2 + w_3 = 1$. Z is the improved evaluation index for sustainable tourism industry. L is the total income, Y is the total implicit cost, and F is the overall resident satisfaction.

The total tourist constraint is: $P_{total} = \sum_{i=1}^{m} P_i$ Among them, P_i is the number of tourists allocated to the i-th attraction. At the same time, we constrain the maximum number of visitors to each scenic spot $0 \leq P_i \leq P_{i,max}$ each scenic spot should meet corresponding implicit cost constraints and resident satisfaction constraints, namely$Y_i \leq Y_{i,limit}$, $F_i \geq F_{i,min}$

3.2.2. Sub-model of Strengthened Sustainable Tourism Model (SST Model)

Model 1: Income Model

The daily total revenue of urban tourism industry is the sum of the revenue of all scenic spots, and the revenue of each scenic spot can use the previous revenue model. Thus, we obtain the improved income model as follows:

$$L = \sum_{i=1}^{m} L_i = \sum_{i=1}^{m} P_i \times M_i \tag{12}$$

Model 2: Implicit Cost Model

The implicit cost of each scenic spot is:

$$Y_{i_{carbon}}(P_i) = a_{i_1} \times P_i + b_{i_1} \times {P_i}^2 + Y_{i_1} \tag{13}$$

$$Y_{i_{water}}(P_i) = a_{i_2} \cdot log(P_i + 1) + b_{i_2} \times P_i + Y_{i_2} \tag{14}$$

$$Y_{i_{infra}}(P_i) = a_{i_3} \cdot P_i^{\alpha_i} + b_{i_3} \tag{15}$$

$$Y_{i_{total}}(P_i) = Y_{i_{carben}}(P_i) + Y_{i_{water}}(P_i) + Y_{i_{infra}}(P_i) \tag{16}$$

The total implicit cost of all scenic spots:

$$Y = \sum_{i=1}^{m} Y_i(P_i) \tag{17}$$

Model 3: Resident Satisfaction Model

Similarly, the overall satisfaction of residents should consider the satisfaction level of each scenic spot. We define the satisfaction level of residents in the i-th scenic spot, including the negative impact of housing supply and cost, overcrowding and noise, and the positive impact of increased employment opportunities and income:

$$\mathrm{F_i}(\mathrm{P_i}) = \mathrm{F}_{\mathrm{i}_0} + a_{i_4} \cdot \sqrt{\mathrm{P_i}} - b_{i_4} \cdot \mathrm{P_i}^2 \tag{18}$$

The overall satisfaction of residents in the entire city is the sum of all scenic spots:

$$F = \sum_{i=1}^{m} F_i(P_i) \tag{19}$$

3.2.3. Model Solution

Consider cities as a combination of four typical scenic spots based on their ability to accommodate tourists and residents' tolerance for tourists. The level of tourist acceptance is related to the natural resources and waste disposal costs of the scenic area. Therefore, we link it to the implicit cost threshold Y_{limit} and evaluate the level of tourist acceptance ability of the scenic area by assessing the level of implicit cost threshold. Similarly, the level of tolerance of residents towards tourists can be linked to the threshold of resident satisfaction F_{min}. Therefore, we can regard a tourist city as a combination of four areas: "very welcome tourists", "warm welcome tourists", "welcome tourists", and "not welcome tourists". The classification criteria are shown in Figure 5.

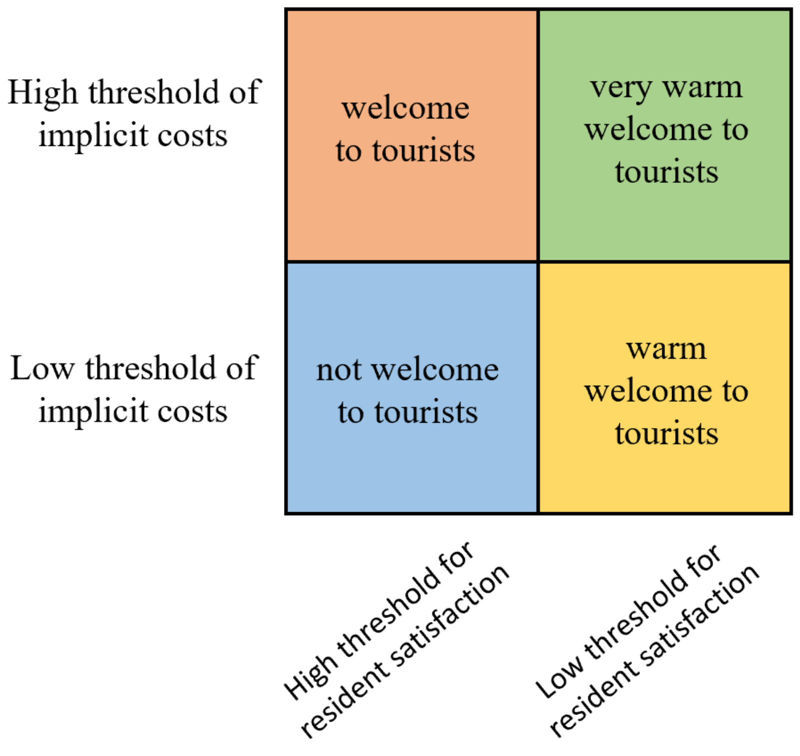

Fig 5. Typical Scenic Area Classification Standards.

We express the types of different areas by setting different hyperparameters. We simulate the situation of each scenic spot separately, and the trends of implicit costs and resident satisfaction with the number of tourists are shown in Figures 6 and 7.

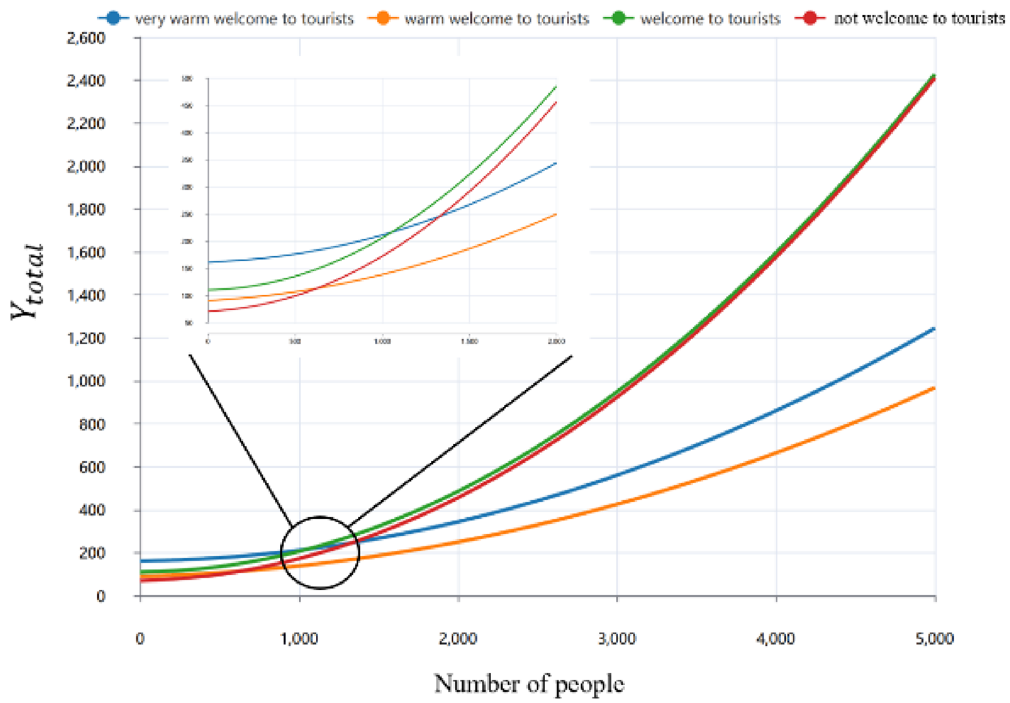

Fig 6. Trend of Hidden Costs of Various Scenic Spots Changing with the Number of Tourists.

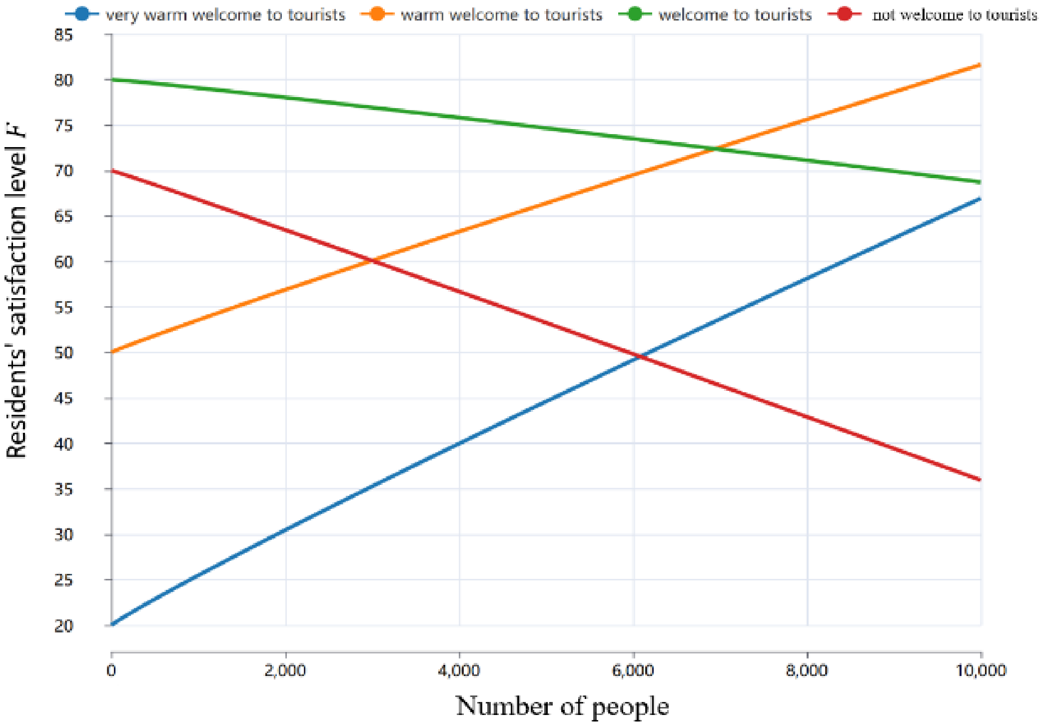

Fig 7. Trend of Resident Satisfaction with the Number of Tourists in Various Scenic Spots.

The analysis results show that scenic spots with lower threshold of implicit cost constraints have lower ability to take measures to stabilize the tourism industry, resulting in higher implicit costs. Scenic areas with a higher threshold for resident satisfaction have a lower level of tolerance towards tourists, which decreases rapidly with an increase in the number of tourists. On the other hand, scenic areas with a higher level of tolerance towards tourists have a lower level of basic satisfaction among their residents, but it rapidly increases with an increase in the number of tourists.

The results of simulating the sustainable tourism industry evaluation indicators for each scenic spot separately are shown in Figure 8.

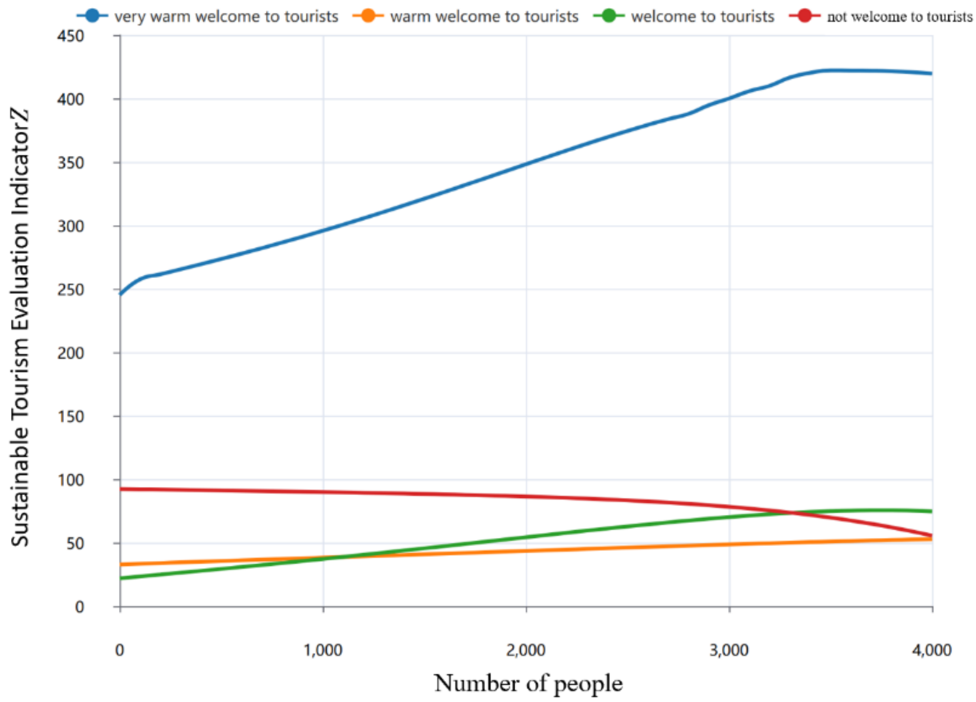

Fig 8. Evaluation Indicators for Sustainable Tourism Industry.

The "very warm welcome to tourists" area has a much higher evaluation index than the other three areas of the highest number of tourists. The evaluation indicators of "more welcoming tourists" scenic spots do not change much within a certain range. The value of "welcome to tourists" area is lower when the number of tourists is small, but higher when the number of tourists is large. The "not welcome to tourists" area, although initially rated high, rapidly decreases with the increase of tourist numbers.

Considering the situation of all scenic spots, we have determined the proportion of people in each scenic spot when resources are optimally utilized, the visualization results are shown in Figure 9.

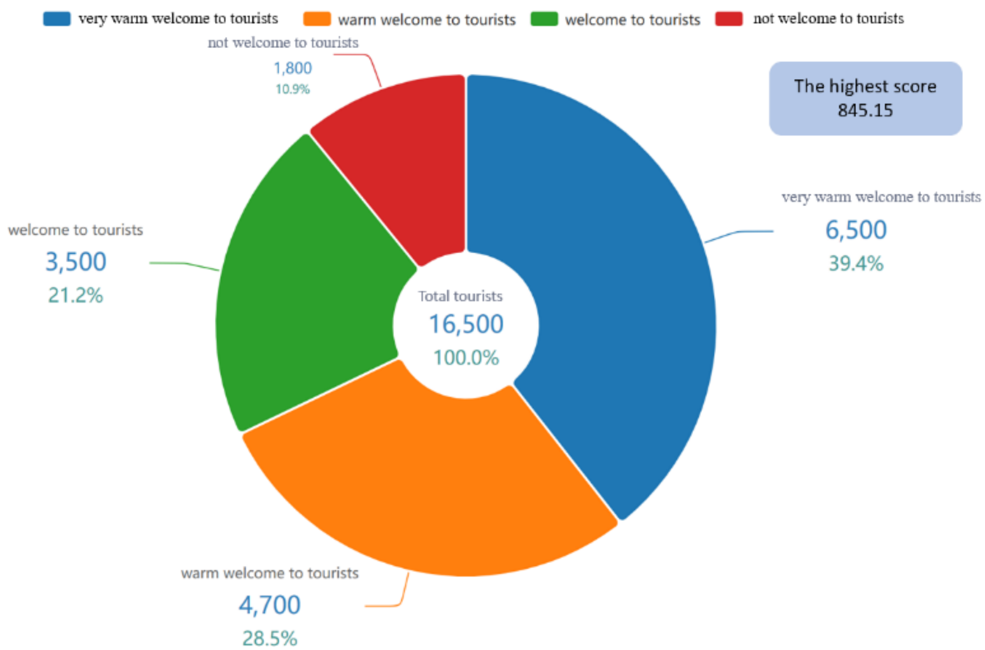

Fig 9. Optimal allocation of tourists.

4. Summary

In this study, a sustainable tourism modeling system was constructed to effectively solve the practical problems of tourist destinations. Based on the ICSS model constructed by the multi-objective genetic algorithm NSGA-II, the optimal number of tourists per day in Juneau was calculated to be 9,500, which provides a quantitative basis for the formulation of local tourism policies. The model has good migration, and the optimal number of tourists in Honolulu is 13200 after re-fitting the parameters.

The improved SST model, considering the city as a combination of multiple attractions, optimizing the evaluation indexes, and determining the optimal allocation ratio of tourists through simulation analysis, can balance the number of tourists in the attractions and improve the efficiency of tourism resources utilization. The results of this research are significant in theory and practice, and more complex factors can be considered in the future to continuously improve the model and promote the development of the tourism industry.

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